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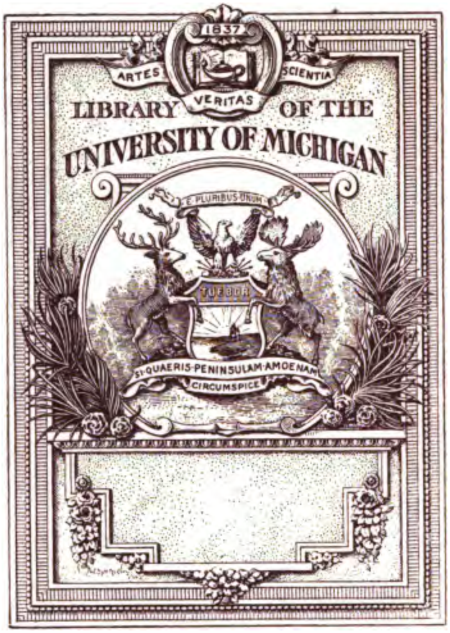
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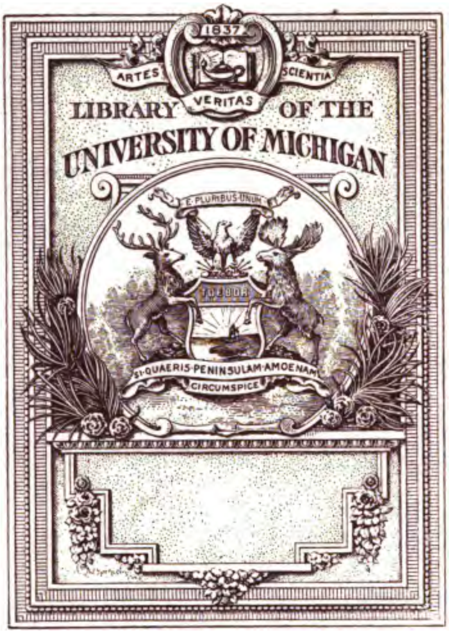
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THE GEOLOGY OF THE CERRILLOS HILLS,

NEW MEXICO

BY

DOUGLAS WILSON JOHNSON

Reprinted from the SCHOOL OF MINES QUARTERLY, 1903–1904

DISSERTATION.

Submitted in partial fulfilment of the requirements for the Degree of Doctor of Philosophy in the Faculty of Pure Science, Columbia University.

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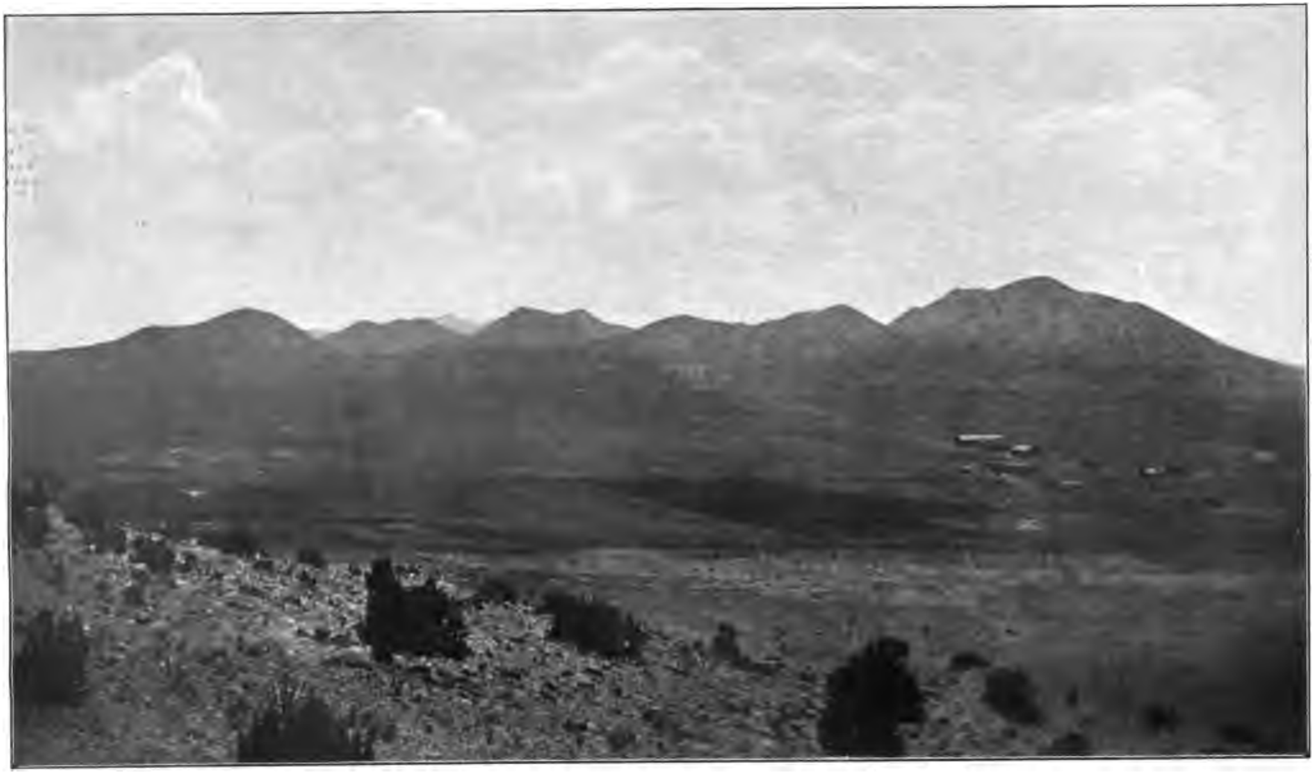
Plate A.



THE CERRILLOS HILLS, NEW MEXICO. (From the northeast.)

Reprinted from THE SCHOOL OF MINES QUARTERLY, Vol. XXIV., April, 1903, No. 3.

THE GEOLOGY OF THE CERRILLOS HILLS, NEW MEXICO.

BY DOUGLAS WILSON JOHNSON.

PART I. GENERAL GEOLOGY.

PREFACE.

The preparation of this paper was first begun when the writer was an assistant on the University Geological Survey of New Mexico, with the intention that it should appear as a reconnoissance report in the bulletins of the Hadley Scientific Laboratories. The work was prompted and supervised by Dr. C. L. Herrick, then President of the Territorial University at Albuquerque, and Director of the Survey. It was found, however, in the course of the brief preliminary investigations then possible, that the field in question presented points worthy of more detailed study than could be given it at that time and permission was granted to withhold the publication of the paper until more satisfactory results could be obtained. The work done at that time represented a few brief excursions to the region during the spring and summer of 1899 and 1900, a portion of the chemical work herein recorded, and some preliminary petrographic examinations.

In the summer of 1902 I again took the field, spending two months in making a detailed study of the Cerrillos region. Maps were prepared, the areal geology worked out with considerable accuracy, and the local conditions affecting the deposits of turquoise, metalliferous veins, and coal seams investigated. Practically all of the palæontological and petrographical work was performed on my return to the laboratories of the Department of Geology of Columbia University.

The area under discussion includes portions of the San Pedro and Santa Clara quadrangles of the United States Geological Survey, the topography being represented by contour lines with intervals of 50 and 100 feet. It was intended to use the required portion of these quadrangles as a basis for the work undertaken, but it soon became apparent that so far as this locality was concerned, the maps were not accurate. As all readings used in working out the areal geology would have to be made on the monuments which are found on the summits of the various peaks of the Cerrillos Hills, or on other monuments to be established, it was deemed advisable to supplement and correct the topographical sheets in that vicinity by further triangulation. A base-line was accordingly established on the plains northeast of the hills, permitting readings whose angles were sufficiently large to insure accurate results. On the basis of this triangulation the preparation of a more detailed map was possible.

In this connection I was fortunate in securing plots of several detailed surveys, the most important being that of the coal properties of the Colorado Fuel and Iron Company, which covered the whole southwestern portion of the area mapped for this report, and a map of Los Cerrillos Mines covering the central and northern portion of this area. Upon these surveys, checked by the recent triangulation, I have relied for the details of roads, arroyos, etc.

It was also found that the contour lines did not represent the actual physiographic features with accuracy, but the time available would not admit of their extended revision. Accordingly, the contours of the survey have been adopted, with only such changes as seemed necessary to express the true conditions as nearly as practicable. It is only fair to state that the comparatively early date of the topographic work in this locality, and the rather limited size of the area under discussion, in part account for the inaccuracies existing.

While some difficulties were thus encountered at the outset, these were overcome and the work materially assisted in various ways through the hearty interest and coöperation of all to whom I appealed. The Territorial University provided the necessary surveying instruments; the office of the coal mines at Madrid furnished valuable maps; the Cerrillos Smelter officials permitted the use of some of their material; and many others rendered valuable aid.

It is impracticable for me to acknowledge in detail the many sources upon which I have drawn in the preparation of this paper, or to thank personally the many friends who have aided me in the work. On every hand I have met with only courtesy and generous assistance. To the Colorado Fuel and Iron Company and the American Turquoise Company of New York, I am indebted for numerous courtesies extended, especially for the freedom of their mines in the Cerrillos district. Their local superintendents, Mr.

Gus J. Johnson and Mr. J. P. McNulty, gave me every possible assistance. Several of the engravings of views about Madrid and Waldo here reproduced are used through the courtesy of *Camp and Plant*, a publication of the Colorado Fuel and Iron Company. Especial acknowledgments are also due Dr. C. L. Herrick for valuable assistance during the earlier part of the field and laboratory work. Dr. W. G. Tight, president of the University of New Mexico, went over a portion of the field with me, and offered valuable suggestions regarding the physiographic problems involved.

To Mr. Frank Hall Knowlton and Mr. Timothy W. Stanton, of the United States Geological Survey, my thanks are due for courtesies in connection with the palæontological part of the work. Mr. George Steiger made the chemical analysis of the andesite, for which I am indebted to the Geological Survey. Professor N. H. Winchell, of Minneapolis, Professor J. J. Stevenson and Professor Arthur Hollick, of New York, Mr. George F. Kunz, of New York, and Mr. Ed. F. Bennett and others of Cerrillos have extended many courtesies. My companions in the field, Mr. E. Dana Johnson and Dr. O. S. Strong, rendered generous and valuable aid.

Throughout the laboratory and office work which this report entailed, I have profited continually by the advice and suggestions of Professor Amadeus W. Grabau, especially in connection with the palæontological and stratigraphical work. It is also my privilege to acknowledge especial obligations to Professor James Furman Kemp, through whose hearty coöperation the preparation of this paper was made possible. Professor Kemp spent a week with me in reviewing the work in the field, and throughout the office work has been of constant assistance. To the cordial interest and kindly criticisms of Professor Grabau and Professor Kemp this paper owes much of whatever it may contain of value.

INTRODUCTION.

THESIS.

The Cerrillos district, as shown on the geological map and understood in this report, comprises a rectangle eighty square miles in area, and includes the low group of hills generally known as "Los Cerrillos," the towns of Cerrillos, Madrid and Waldo, and the coal fields south of the hills. The area is eight miles in width by ten in length, the northern boundary passing through the center of a conical basalt hill known as Mount Calvary, and the western through the point of intersection of the Galisteo Creek with the western base of a low ridge four miles west of the town of Cerrillos, here called the Galisteo monocline.

The present paper aims to give a fairly complete account of the geology of this district. After a brief discussion of the general features, and a synopsis of the work of previous explorers, the general geology of the region is considered. Under this head is presented a detailed discussion of the stratigraphy, followed by an account of the areal geology and physiographic history of the district, and considerations of economic importance. A second part is devoted to the detailed description of the palæontology of the district, and a third to the petrography.

Among others, the following propositions are supported:

(*a*) The Cerrillos Hills represent laccoliths of andesite intruded in Cretaceous strata after the close of the Cretaceous period.

(*b*) The well-known Santa Fé Marls, of Hayden, are of alluvial origin, and represent the time from the early Loup Fork Tertiary to the Recent period.

(*c*) The Galisteo Group of Hayden consists of red beds of late Cretaceous, probably Laramie age.

(*d*) The coal series, or Madrid Group, is of Fox Hills age.

(*e*) The anthracite and bituminous coal of the above group have been produced from lignite by the metamorphic action of intruded sheets of the andesite.

(*f*) Fort Pierre, Fort Benton, and probably Dakota and Jura-Triassic beds, are also present in the district.

(*g*) The turquoise occurs in altered portions of the andesite, and was formed by heated solutions or vapors rising along lines of fracture in the rock.

(*h*) The basalt flows are of late Tertiary or more recent age.

GENERAL FEATURES.

In order that future references may be appreciated the following general relations are here set forth.

Southwest of Santa Fé some twenty-five miles is a group of mountains known as the Gold, Placer or Ortiz Mountains. It is the largest and most prominent of several similar groups. Just south is the group known as the Tuerto or San Pedro Mountains, while still further southward is the uplift of South Mountain. To the north is the smallest of this series, a group of low conical peaks known as the Cerrillos Hills.

Between the Cerrillos Hills and the Ortiz Mountains to the south, the Galisteo Creek flows westward to join the Rio Grande. Throughout the greater part of the year this creek is a small and insignificant stream, whose waters may become almost stagnant and distinctly saline. In times of heavy rains, however, the stream often rises to the magnitude of a torrential river within a few hours, washing out railroad bridges and otherwise effecting much damage. Numerous arroyos empty into Galisteo Creek, the most important being Coal Gulch and Ortiz Arroyo from the south, and Achavica, Mina del Tiro and San Marcos Arroyos from the north. The creek crosses the Cerrillos quadrangle a little south of the center, extending from southeast to northwest. A small stream known as Alamo, Los Cerrillos or Bonanza Creek, a branch of Santa Fé Creek, flows westward and touches the quadrangle at the north.

Following the north bank of Galisteo Creek is the main line of the Atchison, Topeka and Santa Fé Railroad. Of the three towns within the district, two — Los Cerrillos (or simply Cerrillos) and Waldo — are situated on the railroad. The mining town of Madrid is about two miles south of Cerrillos, and is connected by a branch railroad with the main line at Waldo. On the northern boundary of the quadrangle is the little Mexican village of Bonanza, on Bonanza Creek, while ruins of small mining settlements are to be found near here, and also at Carbonateville east of Mount McKensie, and at Rogers, south of Waldo. In earlier days considerable coal was mined at Rogers, and a branch railroad connected the town with the main line at Waldo. The water supply for the three larger towns is secured from a reservoir built in San Marcos Arroyo, about two miles and a half northeast of Cerrillos, to catch the water flowing underground in the arroyo at this point.

The Cerrillos Hills (Plate A) consist of six low, conical peaks, rising rather abruptly from the surrounding level. Several of these peaks have a low saddle at the apex, thus giving them double summits. This is the case with the hills known as Grand Central Mountain, Achavica Mountain, and Santa Rosita Mountain. The remaining hills, Mount McKensie, Santa Rosa Mountain and Lueras

Hill are somewhat more elongated than their neighbors.* Just east of Grand Central Mountain is a low hill known as Mount Chalchihuitl (Plate M). Here are located the famous mines for turquoise, the "chalchihuitl" of the ancient Mexicans.

The above make up the group of the Cerrillos Hills proper, but included in the district are several minor hills. The most striking of these is Mount Calvary (Plate I), a couple of miles due north of the main group. It is a conical hill of basalt, very symmetrical, and of striking appearance. Just east of it is the irregular uplift known as Bonanza Hill. Northwest of the main hills is a low volcanic crater (Plate H), from which a sheet of basalt has flowed out over the surrounding plain; while to the northeast are three small hills which appear more prominent because of their isolated positions. The most important of these is popularly called Turquoise Hill, (Plate O) as the mines of the American Turquoise Company of New York are located there. One mile to the southeast is a low conical hill called Middle Hill, on account of its position between Turquoise Hill and the third member of this trio, still farther southeast, which is called Rocky Butte (Plate L). Northeast of these hills the unbroken plains slope gradually up to the base of the Santa Fé Mountains, one of the loftiest ranges in the territory, while south of the Galisteo a smaller plain slopes upward to the base of the Ortiz group. To the southwest is the great monoclinal uplift of the Sandia Mountains.

The Galisteo Creek and its tributary arroyos have dissected the general plain level to such an extent in the central and southern part of the Cerrillos district, that the country appears quite rough and broken. But one of the most striking features of the region is formed by the remnants of the old plain. Even as one stands in the valley of the Galisteo one is impressed with the uniform level of the hills which form the sides of the valley, especially to the south. When the observer ascends to the top of one of these low hills, he is surprised to find himself looking out over a dissected plain, which slopes gradually upward to the neighboring mountains. Near Madrid this plain is interrupted by a series of monoclinal uplifts which project above the general level. It is

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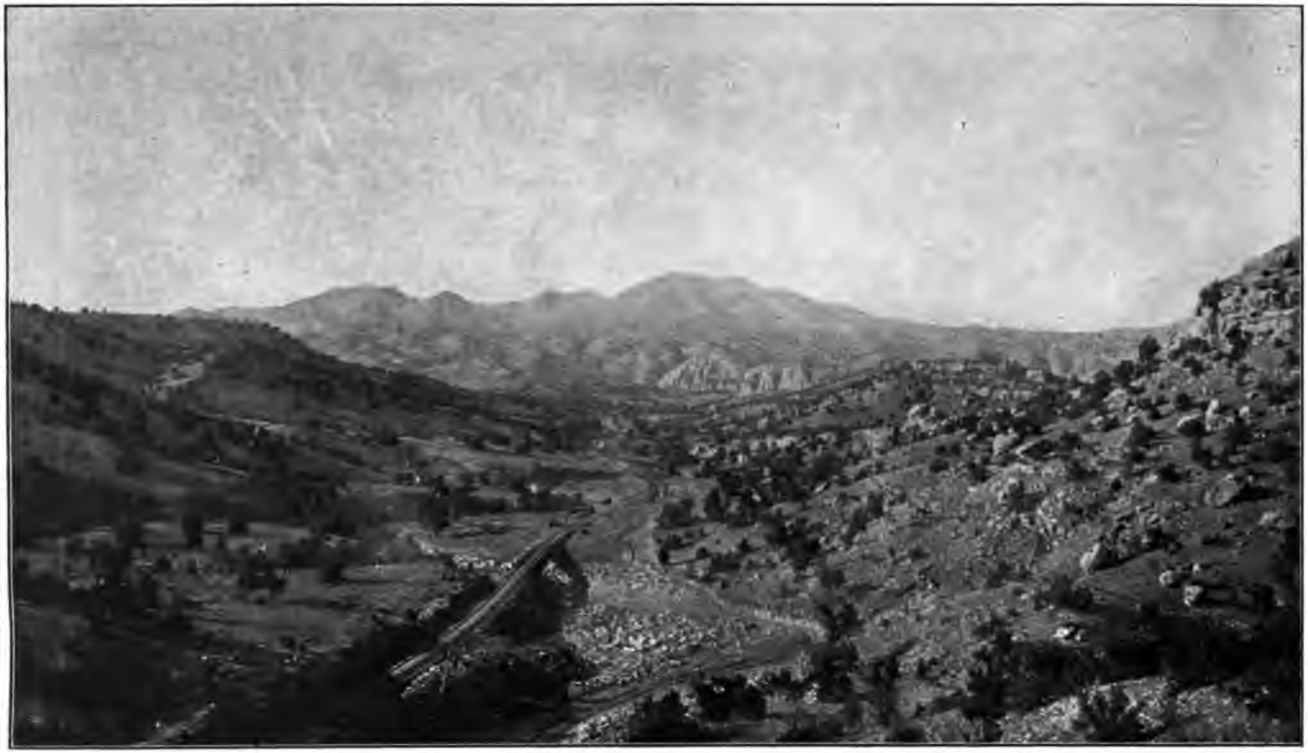
* The above, and other names, as well as the spelling, are based on old and recent maps, the statements of local residents, and other sources. In almost every instance such evidence was conflicting. I have endeavered to employ the names and spelling which seemed to be most in use at present.



Santa Rosa Mt. Achavica Mt.
Lueras Hill. Grand Central Mt.

THE CERRILLOS HILLS, NEW MEXICO. (Looking north through Coal Gulch.)

evident that the Galisteo and its tributaries have cut their valleys into the gently sloping plain formed by confluent alluvial fans from the surrounding mountains. In some cases portions of this plain have been completely cut off from the main mass, and stand as isolated mesas out in broad valleys, closely resembling the phenomena observed in a dissected peneplain. In fact, as we shall see, the conditions here are those of an alluvial plain formed upon an erosion plain, and both subsequently dissected by erosion. The result of the above processes is well shown in Plate C, reproduced from a photograph of the sides of the Galisteo valley just south of the Hills.

Cerrillos (Plates C and K) is the main railroad center for the district, and is the largest town. A modern smelter has recently been built to treat the lead, silver, gold and copper ores from the small mines in the Cerrillos Hills, as well as ores shipped in from more distant points. Madrid (Plate D) is the southern terminus of the Cerrillos Coal Railroad, a small branch which connects with the main line of the Atchison, Topeka and Santa Fé Railroad, three miles north. It is a small mining town of about 1,000 inhabitants, and is the center of the coal industry of the district. The offices, works and coal mines of the Colorado Fuel and Iron Company are located here. The coke ovens are located at Waldo (Plate D), a small village about three miles north of Madrid, at the junction of the Cerrillos Coal Railroad with the Santa Fé main line. In the fifty bee-hive coke ovens a part of the product of the coal mines at Madrid is reduced to coke. The office of the local superintendent of the turquoise properties is located at the mines at Turquoise Hill, the old mines at Mt. Chalchihuitl being no longer worked.

EARLIER REPORTS.

The Cerrillos district has long claimed the attention of geologists and other explorers, and plays a not unimportant part in the geological literature of this region. The placer gold mines of the Ortiz Mountains were the most important factor in calling attention to this immediate locality, while the anthracite coal of the Madrid field has become prominent in later years. The silver, gold, lead and zinc mines of the Cerrillos Hills have been of interest, while the turquoise deposits have made the locality famous both at home and abroad. The district also forms a part of the type locality of the Santa Fé Marls of Hayden, which have an important place in the literature of the early surveys. It would be impossible to collect all the many scattered references to this region and its interesting geological phenomena, but a brief résumé of the more important work is presented below.

The earliest workers in the mines of this region belonged to an ancient race of Indians, of whose history we know little. When the earliest white explorers entered the region they found the extensive turquoise mines of Mt. Chalchihuitl long abandoned, and large cedar and piñon trees growing over the dumps, and down in the diggings. The vast extent and the evident antiquity of the workings were marvellous. The stone hammers of these ancient miners are still to be picked up amongst the débris. As the mines have never been worked to any extent since the Pueblo uprising in 1680, practically all of the vast excavation must have been made prior to that date, and must represent a very great length of time.

The earlier explorers also found that the lead, silver and other mines in the Cerrillos Hills had been worked to a greater or less extent, while the placer mines to the south were still in operation and a few settlers were carrying on gold mining in a more extensive manner. It is, however, in the scientific work of the various exploring expeditions that we are most interested.*

In July, 1846, Dr. A. Wislizenus visited the Cerrillos district, while on a scientific tour to Mexico. He made a careful study of the placer mines in the Ortiz Mountains to the south, and in his report † describes these workings in detail and mentions a few other points of general geological interest.

In September, of the same year, Lieut. J. W. Abert made a trip from Santa Fé to the placer mines in the Ortiz Mountains, while connected with the Army of the West. Lieut. Abert describes ‡ the placer mines, and gives notes concerning the eruptives and sedimentaries of the Cerrillos region, the occurrence of coal and other points of interest.

Major W. H. Emory visited the region in 1846, in connection with the Advanced Guard of the Army of the West. His report * contains but few notes on the Cerrillos district.

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* A more extensive résumé of the work of some of the writers now to be cited may be found in Prof. J. J. Stevenson's report to Lieut. Wheeler, U. S. Geog. Surv. West of 100th Mer., Vol. III., Supplement, pp. 28–36. A still more detailed account appears in connection with the discussion of the various geological problems, in subsequent pages.

† Senate Miscellaneous Document No. 26, 30th Congress, 1st Session.

‡ Senate Executive Document No. 23, 30th Congress, 1st Session.

In the fall of 1853 Prof. Jules Marcou, in connection with Lieut. Whipple's exploration for a railway route near the thirty-fifth parallel, made more extensive notes on the geology of the Cerrillos district. He describes † the alluvial deposits washed down from the neighboring mountains, the sedimentary rocks, the eruptives, and the numerous dikes which are so prominent a feature of the region.

In 1857 Prof. William P. Blake visited the Hills, and published notes on the geology ‡ and mineral resources § and a paper on the turquoise deposits ||.

In 1858 Prof. J. S. Newberry, in connection with the Ives Exploring Expedition, visited the Cerrillos district and made some general notes on the geology.** A year later Prof. Newberry again had the opportunity to visit this region, while connected with the Macomb Exploring Expedition. At this time he made a much more extended study of the geology, and his report †† on the area was the most extensive we had up to the time of its publication. Prof. Newberry discussed the character and age of the various deposits, the occurrence of the anthracite coal, iron, placer gold, and other mineral products, and the types and age of the eruptive rocks.

Dr. John L. Le Conte, in connection with the survey of the Union Pacific Railway, visited the region in 1867, and made some observations upon the geological conditions. In his report ‡‡ he

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[*] Executive Document No. 41, 30th Congress, 1st Session.

[†] Explorations and Surveys for a Railroad Route from the Mississippi River to the Pacific Ocean, Vol. III., Pt. IV., No. 2, pp. 140–141.

[‡] Observations on the Geology of the Rocky Mountain Chain in the Vicinity of Santa Fé, New Mexico, *Proc. A. A. A. Sci.*, 1859, pp. 314–319.

[§] Observations on the Mineral Resources of the Rocky Mountain Chain near Santa Fé, New Mexico, *Proc. Bost. Soc. Nat. Hist.*, 1859, pp. 64–70.

[||] The Chalchihuitl of the Ancient Mexicans, *Am. Jour. Sci.*, Vol. XXV., 1858, pp. 227–232.

[**] Report upon the Colorado River of the West, by Lieut. J. C. Ives, Wash., 1861. Pt. III., Geol. Report, pp. 98–99.

[††] Report of the Exploring Expedition from Santa Fé, New Mexico, to the Junction of the Grand and Green Rivers, by Capt. J. N. Macomb, 1859. Geol. Report, pp. 38–42.

[‡‡] Notes on the Geology of the Survey for the Extension of the Union Pacific Railway, E. D., from the Smoky Hill River, Kansas, to the Rio Grande; Phila., 1868, pp. 36–41.

mentions the occurrence of the coal, placer gold, turquoise and other valuable products, discusses the origin of the anthracite and the character of the eruptives. A section through the coal series and other details are given.

In 1869 Dr. F. V. Hayden made a reconnoissance "from Santa Fé to Placiére Mountains and return." His report * is brief but of unusual interest and value. He describes and names the group known as the Santa Fé Marls, and the Galisteo Group of red sandstones. The occurrence of the coal is discussed, detailed sections given, and the mineral products described. In other portions of this same report are points of interest which bear on this special region.

Dr. Oscar Loew connected with the Wheeler Expedition, visited the region in 1874, and his reports † record several observations upon the geology of the Cerrillos district.

During the same year Prof. E. D. Cope, also connected with Lieut. Wheeler's Expedition, made a trip through this region and published notes concerning the Santa Fé Marls and older deposits.‡ The greater part of Prof. Cope's observations were made at points outside of the Cerrillos district proper, but have a direct bearing on geological problems involved in the study of that area.

In 1878–79 Prof. John J. Stevenson, in connection with the Wheeler Survey, made a study of the geology of southern Colorado and northern New Mexico. His report § gives the most extensive account yet published of the geology of the region about Galisteo and from there westward to the Cerrillos district. The details of Prof. Stevenson's observations are considered more fully in subsequent pages.

In 1880 Prof. Benjamin Silliman visited the Cerrillos Hills, and published notes on the "Turquoise of New Mexico." ‖ He dis-

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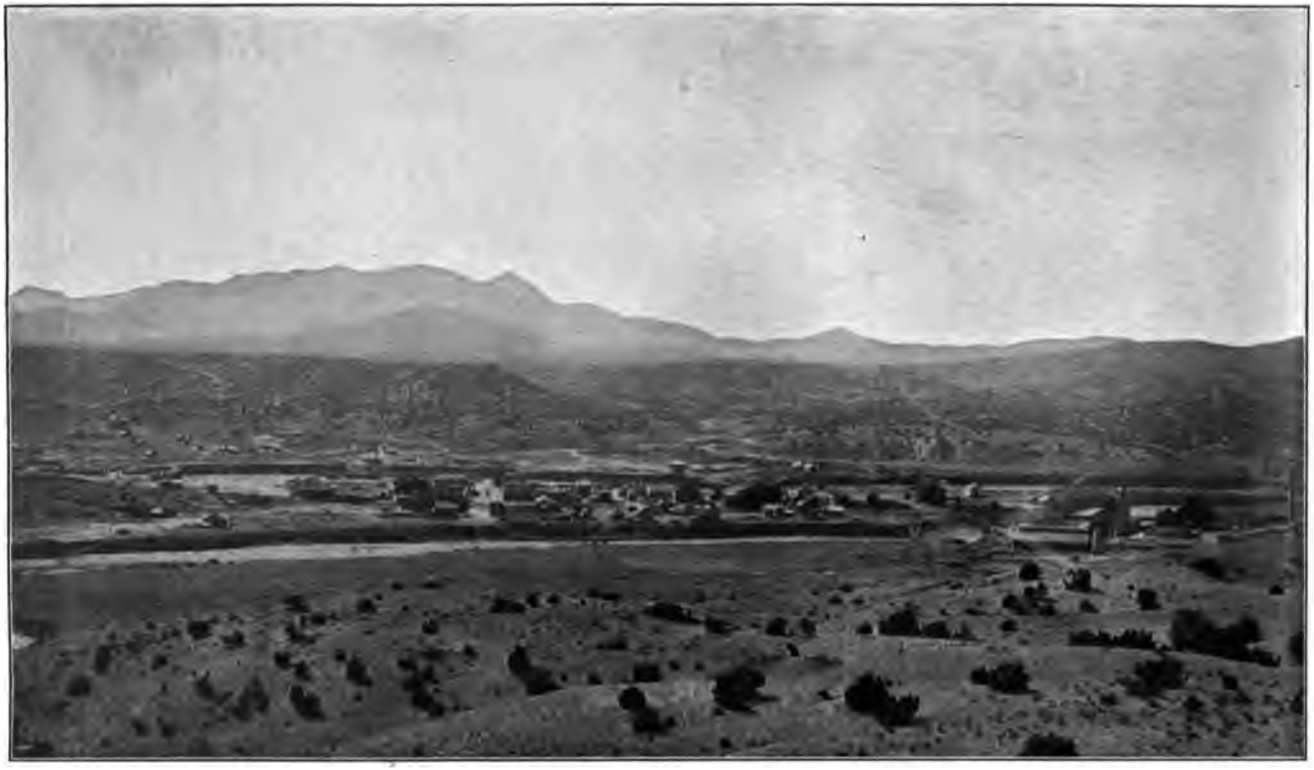
* Preliminary Field Report of the United States Geological Survey of Colorado and New Mexico, 1869, pp. 66–68.

† U. S. Geog. Surv. West of 100th Mer., Vol. III., Pt. VI.; also Rep. of Chief of Engineers, 1875, Pt. II., Appendix G 2.

‡ U. S. Geog. Surv. West of 100th Mer., Vol. IV., Pt. II.; *Proc. Phil. Acad. Nat. Sci.*, 1874, pp. 147–152; same for 1875, p. 271; also Rep. of Chief of Engineers, 1875, Pt. II., Appendix G 1.

§ U. S. Geog. Surv. West of 100th Meridian, Vol. III., Supplement.

‖ *Am. Jour. Sci.*, July, 1881, pp. 67–71.



TOWN OF CERRILLOS. ORTIZ MOUNTAINS IN DISTANCE. (Showing dissected alluvial plain.)

cusses the age of the Cerrillos uplift, the occurrence of turquoise, and the extent and antiquity of the mines.

Prof. Stevenson again visited the Cerrillos district in 1895, and published extensive notes on the occurrence and origin of the anthracite coal,* together with considerations of the local geology.

In 1897 Dr. C. L. Herrick studied the Cerrillos district, and briefly described † some of the general geologic features.

The work of the writer represents several excursions into the region during the spring and summer of 1899 and 1900, and a more extensive and detailed study during the summer of 1902. The results of the studies are herewith presented.

STRATIGRAPHY.

The Santa Fé Marl Group.

Loup Fork Tertiary to Recent.

Throughout the Cerrillos district, except where the Galisteo Creek and its tributary arroyos have removed them, a series of horizontally bedded marls, marly sands and conglomerates are found resting upon the planed-off edges of the upturned older sediments. To this series Dr. Hayden gave the name "Santa Fé Marl Group," and its interest to geologists has always been considerable. Its deposits constituted the basis for one of the great Tertiary lakes assumed by the geologists of our early surveys to have occupied so much of the area of the western territories during the Tertiary period. At a time when we are just beginning to realize that some of these supposed lacustrine deposits are really of fluviatile or alluvial origin, a study of the Santa Fé Marls proves especially interesting.

So far as I am aware, the first notes on the Santa Fé Marls were made by Jules Marcou in the fall of 1853. In his field-notes for October 1 and 2 of that year,‡ he speaks of a "diluvium coming from Gold (Ortiz) Mountain"; "hills of diluvium (in the village of Galisteo) coming from the Santa Fé Mountains" and containing "masses of granite, serpentine, etc.;" "the thick diluvium containing angular fragments of small size, and mingled with sand

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* *Trans. N. Y. Acad. Sci.*, January, 1896, pp. 105–122.

† *Bull. Univ. New Mexico*, Vol. I., pp. 109–114.

‡ Exploration and Survey for a Railroad Route from the Mississippi River to the Pacific Ocean, Vol. III., Wash., 1856; Pt. IV., No. 2, pp. 140–141.

and rose-colored granite, with crystals of hornblende;" and of "a whitish conglomerate, in horizontal beds, covering the trachytes along the creek."

In 1858 Prof. Newberry, on his first trip to this region, noted that the only rock visible from the Cerrillos Hills to Santa Fé was red calcareous sandstone of the Marl series (Triassic) which is generally covered by "drift from adjacent mountains."* In 1859, on his second trip, Prof. Newberry made a much more extensive examination of this region, but in his report does not discuss the Santa Fé Marls. In one place he says:† "It is only near the Rio Grande that the Tertiary beds to which I have referred make their appearance." Evidently, then, he did not consider the Santa Fé Marls which are so well exposed in the Cerrillos region and from there to Santa Fé as belonging to the Tertiary. It would seem that he regarded these beds as recent drift derived from neighboring mountains, and not worthy of more than passing notice.

In 1869 Dr. Hayden visited the Cerrillos district, investigating and naming the deposits known as the Santa Fé Marls. In his preliminary report on the field work for that year he says:‡ "From Santa Fé to the banks of the Galisteo Creek, eighteen miles, we pass over the recent marls and sands which seem to occupy the greater portion of the valley of the Rio Grande, above and below Santa Fé, and which I have called Santa Fé marls. These are mostly of a light cream-color, sometimes rusty yellow, and sometimes yellowish-white, with layers of sandstones, varying in texture from a very fine aggregate of quartz to a moderately coarse pudding-stone. These marls and sands weather into unique forms north of Santa Fé, like the 'bad lands' or 'Mauvais terres' of Dakota." A little further on we find the statement "basaltic rocks are poured over the recent Tertiary beds," and finally "We have, therefore, in the valley of the Rio Grande, if my investigations are correct, three groups of Tertiary beds of different ages: (1) The coal strata; * * * (2) the Galisteo sand group; * * * (3) the Santa Fé marls, which are of much later date than either of the other two, and rest unconformably upon the Galisteo group, and never incline more than five or ten degrees." In the report of a trip from Santa Fé to Taos * we find the following: "These Santa Fé marls reach a great thickness north of Santa Fé, in the Rio Grande valley, from one thousand two hundred to one thousand five hundred feet, and have a tendency to weather into similar monumental and castellated forms, as in the 'Bad Lands.' The upper portions are yellow and cream-colored sandstones, sands and marls. Lower down are some gray coarse sand beds with layers of sandstone. All these marls dip from the range westward three to five degrees. The Rio Grande wears its way through these marls with a bottom about two miles wide. * * * As we go northward near the mountains, the rounded boulders become more and more numerous, but near the Rio Grande, where they have all disappeared, the source of this great thickness of sediment is apparent." And in another place,† "Along the base of the mountains, especially in the valley of the Peñasco, there is a great thickness of very coarse conglomerate resting upon the granite horizontally. It is undoubtedly of the same age as the marl beds." In other places Dr. Hayden frequently refers to the fact that these marls are overlain by basalt.

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* Rep. upon Col. Riv. of the West, by Lieut. J. C. Ives, Wash., 1861; Pt. III., pp. 98–99.

† Rep. of the Expl. Exped. from Santa Fé, N. M., to Junct. of Grand and Green Riv., by Capt. J. N. Macomb, 1859; Geol. Rep., pp. 38–42.

‡ Prelim. Field Rep. U. S. Geol. Surv. of Col. and New Mex., pp. 66–68, 1869.

I have quoted thus extensively from Dr. Hayden's report in order that we may clearly understand the essential relations and characters of the Santa Fé Marls as understood by the one who defined and named them. We see from his statements that the following facts hold true in the type locality:

1. The beds vary greatly in thickness.
2. They vary greatly in composition in vertical section, showing marls, fine and coarse sands, and fairly coarse pudding-stones.
3. They vary greatly in composition in areal distribution, and have a tendency to consist of great beds of coarse conglomerates near the mountains, to become finer and finer farther away from the uplift, and to consist of fine sediments at the more remote localities.
4. They dip with a small but comparatively uniform inclination in all directions from the mountains.
5. They rest unconformably upon the upturned sandstones of the Galisteo Group, east of Cerrillos.
6. They are overlain by basalt flows in a number of places.

It is with the above points as a standard of comparison that I

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* *Ibid.*, p. 69.

† *Ibid.*, p. 70.

wish to review the opinions of other geologists regarding these beds.

In 1874 Professor E. D. Cope visited this region, and later in that same year published a paper entitled "Notes on the Santa Fé Marls and Some of the Contained Vertebrate Fossils." * A still more extensive account † of these beds appeared in Professor Cope's full report to Lieut. Wheeler.

Professor Cope confined himself largely to a discussion of the vertebrate remains and the age of the beds. He considered these Marls of lacustrine origin, and referred them to the Loup Fork epoch, on the basis of vertebrate fossils obtained near San Ildefonso, Sante Fé and Santa Cruz.

In 1879 Professor J. J. Stevenson, in connection with the Wheeler Survey, studied this region, and published "Notes on the Geology of Galisteo Creek, New Mexico "‡ in which he described the beds in question. These notes appeared more fully §in Professor Stevenson's report to Lieut G. M. Wheeler upon the "Geological Examinations in Southern Colorado and Northern New Mexico, During the Years 1878 and 1879," from which report I note the following:

Professor Stevenson divided these horizontal beds into two different groups, which he considered of different ages — the Galisteo Group being "not older than early Miocene or newer than early Pliocene," and the Santa Fé Marls, belonging, as determined by Cope, to the Loup River epoch of the Pliocene. It is unfortunate that the name "Galisteo Group," which had already been employed by Dr. Hayden to denote the easterly dripping red sandstones above the coal measures, should be applied to an entirely different series of beds at the same point. I cannot see that the possibility of the red sandstone series belonging to the Laramie or coal group forms any objection to the use of a local term to designate a special development of a part of such group, and in my treatment of this region can only adopt the terms established by Hayden in 1869.

Professor Stevenson gives the following section of his so-called Galisteo Group:

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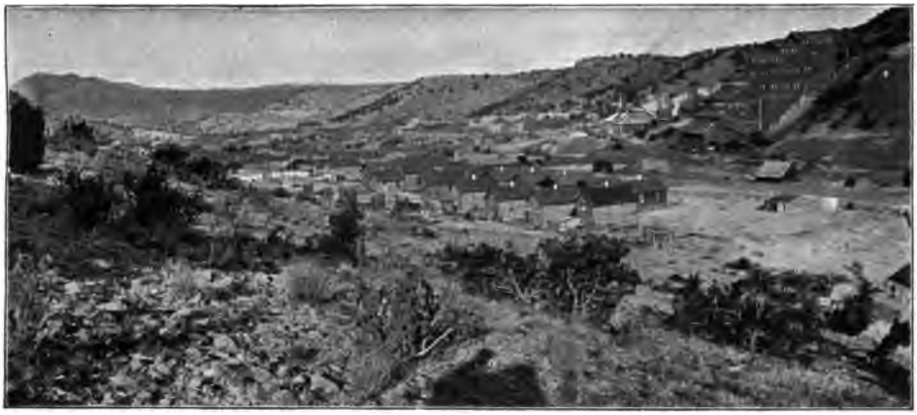
* *Proc. Phil. Acad. Nat. Sci.*, 1874, pp. 147–152, pls. IX.-XI.

† U. S. Geog. Surv. West of 100th Mer., Vol. IV. Pt., II., pp. 20–25.

‡ *Am. Jour. Sci.*, Vol. XVIII., pp. 471–475, 1879.

§ U. S. Geog. Surv. West of 100th Mer., Vol. III., Supplement, pp. 159–163, 1881.



From "Camp and Plant."

Madrid, New Mexico. On the right the uniform level of the dissected plain is shown, while the Cerrillos Hills appear in the background at the left.

From "Camp and Plant."

Coke Ovens at Waldo, New Mexico.

	Feet.
Trachyte breccia	150
Soft light gray sandstone	40

The breccia is described as "very dark gray or even lead colored, and is composed of angular fragments, cemented by finer material, apparently of similar nature." The sandstone is "very light gray, excessively soft and incoherent, so that it yields to the weather as though it were loose sand, weathering, indeed, more freely than do the tough alluvial deposits along the creeks. This is the lowest bed of the group found within the area examined." Regarding the relation of these beds to each other and to the underlying beds, Professor Stevenson says: "Both the breccia and the underlying sandstone (of the above group) * * * are conformable. * * * The breccia is composed largely of trachyte from Los Cerrillos, a group of trachyte hills shown on the north side of Galisteo Creek at sixteen miles below the village (Galisteo). But the outburst of trachyte, forming those hills, caused frightful contortion of the Laramie beds (Galisteo Group proper, of Hayden). It is clear, then, that the Galisteo Group (of Stevenson) cannot be conformable to the Laramie. * * * It certainly antedates the great flow of basalt, for as far as examined it shows no included fragments of that rock. It no doubt is long posterior to the trachyte outburst, for it rests on the leveled edges of the rocks which were turned up during that outburst."

On reading Professor Stevenson's account of this group it readily becomes apparent that it is none other than the typical Santa Fé Marls of Dr. Hayden. And, as I shall show in subsequent pages, the examination of the beds in the field confirms this fact. For the present I will merely compare Professor Stevenson's description of the beds with the standard of comparison which we have in Dr. Hayden's report. Reference to that standard (p. 13) will show that so far as the composition of the beds is concerned, there is nothing in Professor Stevenson's description which does not agree with that of Dr. Hayden's as shown in paragraph No. 2. This group, according to Professor Stevenson, rests unconformably upon the upturned edges of the sandstones (Laramie of Stevenson, or Galisteo Group of Hayden) east of Cerrilos. The Santa Fé Marls, in their typical development, occupy exactly this position with relation to these same beds in the same locality as noted in paragraph No. 5. Professor Stevenson states that this group is older than the basalt flows. Dr. Hayden states clearly that the Santa Fé Marls are older than the basalt flows, being overlain by such flows in a number of places (paragraph No. 6). There can be no doubt, then, that the so-called Galisteo Group of Stevenson is nothing else than the Santa Fé Marl group of Dr. Hayden.

Professor Stevenson then describes what he considers as the Santa Fé Marls, and gives the following section:

	Feet.
Silt	1
White marly limestone	1
Conglomerate	3
Clay	10
White marly limestone	3
Total	18

He further says*: "The marly or chalky limestone is present beyond Galisteo Creek southward on the bench reaching toward the Placer Mountain, and very possibly the whole of the loose material seen there, consisting of fragments of trachyte, granite, etc., with sands, clays, and irregular layers of the marly limestone, may be included in this group (Santa Fé Marls); the thickness being between fifty and seventy-five feet. * * * The group is certainly newer than the basalt, for fragments of that rock cemented by it occur on the Ocate Mesa near the Wagon Mound. It overlies the basalt in the Upper Valley of the Rio Grande."

It is evident that the tabulated section given above is merely a small fraction of the upper part of the Santa Fé Marls. As for the beds beyond the Galisteo Creek southward on the bench reaching toward the Placer Mountain, after a careful examination of numerous exposures, I am convinced that they are absolutely identical and were once continuous with the beds on the north side of the creek, that they are older than the basalt, being overlain by it further north, and that they rest directly on the leveled edges of the upturned yellow and red sandstones of the Galisteo Group proper, as well as of the earlier Cretaceous rocks. It will be seen that the very uppermost few feet (alone) of the Santa Fé Marls are more recent than the basalt and overlie it in places; or, in other words, that the whole of the Santa Fé Marls constitute a single, practically indivisible formation; that after a large part of the beds had been deposited the basalt was poured out over the beds already formed; and that this basalt was in turn covered in places by the small amount of marls which continued to be deposited after the eruption.

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* *Ibid.*, p. 162.

One fact which led Professor Stevenson to separate the upper few feet of these Marls from his so-called Galisteo Group, was the evidence, at a certain point, of unconformity between the two. Believing, as the earlier geologists did, in the lacustrine origin of these beds, such a conclusion was most natural. When the true character of these deposits is understood, however, it will be seen that such unconformities are very numerous and bear no relation to the age of the beds, but rather to the mode of their formation.

Both Dr. Hayden and Professor Stevenson refer in several places to a peculiar conglomerate or breccia cemented by carbonate of lime, and which in some instances they considered of Recent or Quaternary age. As will appear later, such a deposit is characteristic of the Santa Fé Marls at many points in the type locality.

In 1897 Dr. C. L. Herrick visited this region and published notes on "The Geology of the Cerrillos and Ortiz Area." * After speaking of the Cretaceous shales, he says: "Above these shales is a bed of crag and loose material over 50 ft. thick. The boulders at the bottom of this series are of phonolite similar to that of the mountains at the south end of the range (Cerrillos). The whole is capped by 25 ft. of recent lava from the adjacent cone." Dr. Herrick does not refer to the origin of these beds further than to state his opinion that they resulted from the erosion of the Cerrillos hills. He speaks of them as "perhaps Pleistocene," and apparently did not recognize their identity with the Santa Fe Marls of Hayden.

In the summer of 1902 the writer made a careful study of the Santa Fé Marls, which are typically developed in the Cerrillos district, although not attaining the great thickness reported from farther north. The locality east of Cerrillos, studied by Dr. Hayden, and many other excellent exposures, were visited, and some interesting data collected.

As shown on the map, the Santa Fé Marls cover a large portion of the Cerrillos district. Before the present erosion cycle, these marls extended over the entire area, and were the only sediments visible, with the possible exception of the uptilted coal measures

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* *Bull. Univ. New Mex.*, Vol. I., pp. 109–114.

at Madrid, which may have protruded a short distance above their surface. The andesite peaks of the Cerrillos Hills doubtless still projected above the surrounding blanket, which they had helped to form by contributing a goodly supply of material for the conglomeritic and finer beds. It was the more recent erosion which revealed the underlying Cretaceous, and to-day we find these older rocks exposed in the valleys of the river and tributary arroyos, while the Marls still cover the general level into which these valleys have been cut.

The relation of the Santa Fé Marls to the underlying rocks is clearly shown in a number of places, one of the best being a mile or two east of the town of Cerrillos (Plate G). The red and yellow sandstones of the Galisteo and Madrid groups, upturned by the Cerrillos intrusion, have been leveled off, and the practically horizontal Marl beds deposited upon them. One mile west of Madrid these Marls rest horizontally upon the upturned and planed-off edges of the Fort Pierre beds in exactly the same manner, while the same relation to Fox Hills and Colorado beds is seen at several points. The extreme regularity of the rock floor upon which these Marls were deposited is remarkable, and its significance is considered elsewhere.

The relation of the Santa Fé Marls to the basalt flow is well shown west of the Cerrillos Hills (Plate F). Here the Marls consist of some 20 to 30 ft. of conglomerate, above which are pink marls and sands of considerable thickness, the whole being capped by 10 ft. of olivine basalt. There is no evidence of any great erosion unconformity between the Marls and the basalt, while farther north the eastern side of the flow is concealed by a small amount of marls apparently identical with the Santa Fé Marls below, of which they doubtless form a continuous part.

The accompanying diagram (Fig. 1) will serve to illustrate the existing conditions:

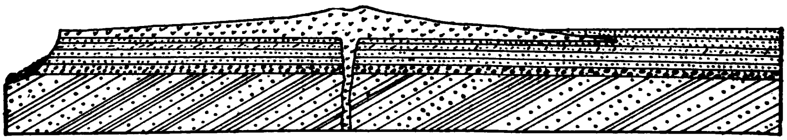
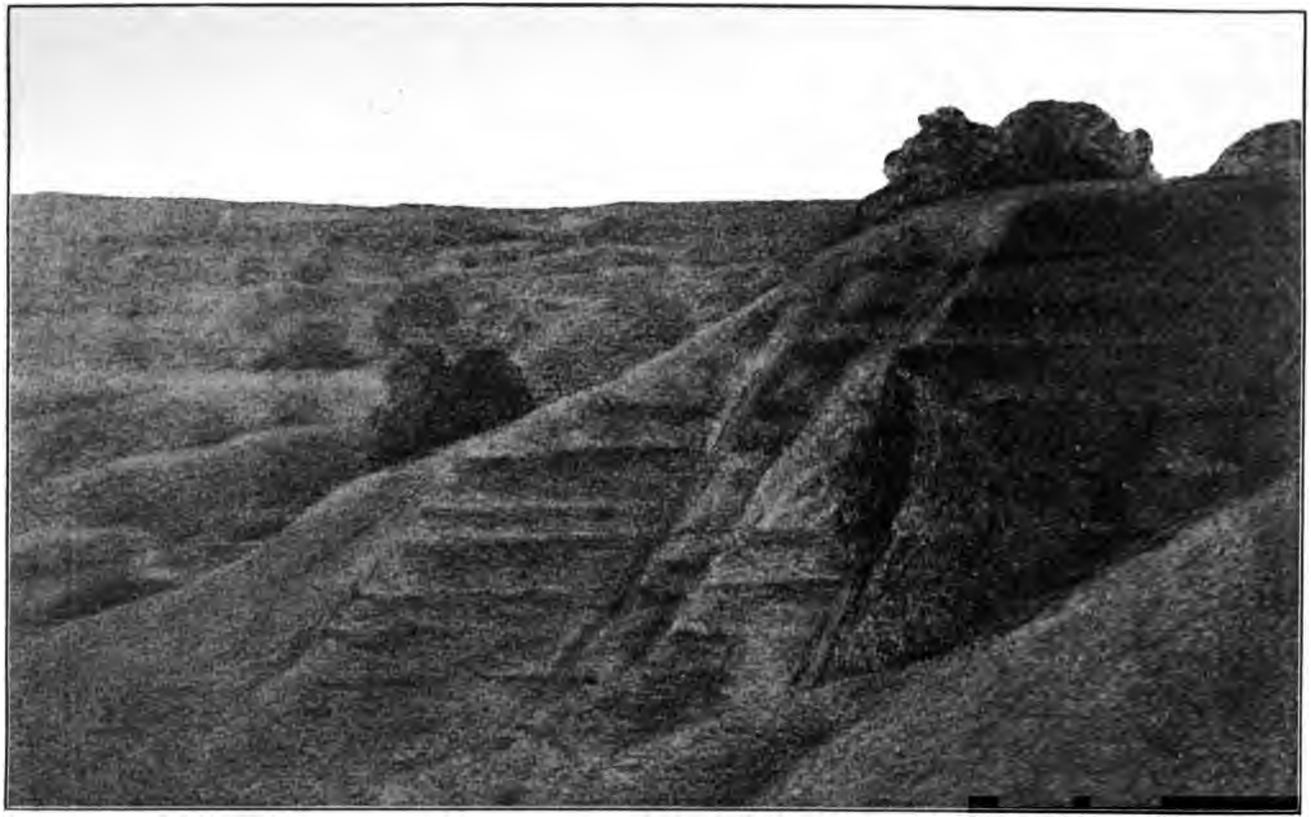


FIG. 1. Diagrammatic illustration of the relations of the Santa Fé Marls to the basalt flow and to the underlying Cretaceous beds. (Latter should dip east at the left of figure.)



DRAWN FROM PHOTOGRAPH, BY R. B. JOHNSON.

SANTA FÉ MARLS. (Showing weathering effects in the softer beds.)

Wherever seen, the Marls consist of beds of a peculiar conglomerate of more or less coarse andesite fragments cemented by a marly cement; of beds of very fine, soft marls and sandstones; and of coarser sands. Frequently the finest sands and marls are mixed with coarse pebbles or boulders. In the peculiar conglomerate above mentioned the fragments are not rounded, showing that the material was not transported far. The local character of the formation is also indicated by the fact that nearly all of the fragments are of the same rock composing the Cerrillos Hills and Ortiz Mountains. In some of the higher beds are often found well rounded, worn pebbles and boulders of red granite, mica schist, etc., which must have had their source in the Santa Fé Mountains 20 to 25 miles northeast of the district.

Although possible, it does not seem to me at all probable that these Marls were ever much thicker in the Cerrillos district than they now are. The greatest thickness I have seen is a little less than 100 feet, although a short distance northeast of the area under discussion a thickness of about 200 feet is found. In other localities, especially nearer the large mountain ranges, a much greater development of these beds is noted.

ORIGIN.

Concerning the origin of the Santa Fé Marls the earlier geologists apparently entertained two different opinions. Although their belief is not definitely stated, we may infer from the notes of Marcou and Newberry that they considered these beds to be wash from the adjacent mountains deposited by subaërial action. Marcou speaks of "thick diluvium coming from the Gold and Santa Fé Mountains," while Newberry calls it "drift from adjacent mountains."

On the contrary, Hayden and Cope regarded these beds as having been deposited in a great Tertiary lake occupying the region between the Santa Fé Mountains on the east, the Cochiti range on the west, and extending an unknown distance southward. Hayden stated his belief in a lacustrine origin for these Marls in the following words.* "I have already alluded to my belief that this western country during the Tertiary period was covered to a greater or less extent with a chain of brackish or fresh-water lakes; that the Tertiary period began its existence with brackish water deposits, which gradually became fresh water, and thus continued up to the present time." He then states that he divides these lacustrine deposits into lower, middle and upper Tertiary, describes the lower and middle Tertiary beds, and continues: "In the valley of the Rio Grande at least from Albuquerque to the north end of San Luis Valley, a series of marly sands of a light color prevail to a greater or less extent. * * * To this group I have given the name of Santa Fé marls; and they are doubtless of the age of upper Tertiary."

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* Prelim. Field Rep. U. S. Geol. Surv. of Col. and N. Mex., pp. 89-90, 1869.

That Professor Cope believed in a lacustrine origin for these beds there can be no doubt. He repeatedly refers to them as "lacustrine deposits." This belief was not unqualified, however, for in speaking of the fauna of the Santa Fé Marls, Professor Cope himself calls attention * to the noteworthy absence of fish and crocodile remains, describes the occurrence of "numerous vertical streaks, or rods, of a white calcareous mineral" resembling "tubes formed by the decay of roots of a marsh vegetation, or by the borings of mud-loving animals," and suggests that these Marls may have been formed in a marsh rather than a lake. That his belief in a lacustrine origin was still predominant, however, is evidenced by his continued references to the lacustrine conditions he considered to have then prevailed. In the same report with the above, he says: † "These beds (Triassic) crop out in high bluffs, and doubtless formed the precipitous western shore of the fresh lake which, during the Loup Fork epoch, filled the valley of the Rio Grande from its upper waters to an unknown distance toward Mexico." And again, "The earliest information which we possess respecting the existence of Vertebrate remains in the lacustrine deposits of the Rio Grande Valley," etc.

So far as I am aware Professor Stevenson has not expressed himself directly regarding his opinion of the origin of the Santa Fé Marls. In his report to Captain Wheeler, ‡ however, he says: "Here and there on the plain (Canadian) a marly, travertine-like limestone underlies the Quaternary, and probably marks the place of some later tertiary lakes." In the index to the supplement this deposit is included under "Santa Fé Marls."

A detailed study of the various exposures of the Santa Fé Marls

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* U. S. Geog. Surv. West of 100th Mer., Vol. IV., Pt. II., p. 361.

† *Ibid.*, p. 24.

‡ U. S. Geog. Surv. West of 100th Mer., Vol. III., Supplement, p. 225.

in the Cerrillos region convinced me that these beds are of alluvial, and not lacustrine, origin. I believe they are wholly the result of laterally confluent alluvial fans spreading out from the Santa Fé, Cerrillos, Ortiz and neighboring ranges, and composed entirely of the débris eroded from those ranges and deposited by subaërial agencies. I do not believe that any Tertiary or more recent lake of noteworthy dimensions ever occupied this region, or materially affected the alluvial deposits.

Before considering the evidence furnished by the data collected, I desire to review the criteria which may be used in discriminating between deposits of alluvial and lacustrine origin. In a paper on "The Freshwater Tertiary Formations of the Rocky Mountain Region," * Professor W. M. Davis has called attention to the almost universal interpretation of fresh-water strata as lake deposits by the geologists of our western surveys, has noted the existence in many localities of fresh-water strata which are undoubtedly the result of laterally confluent alluvial fans, and has expressed his belief

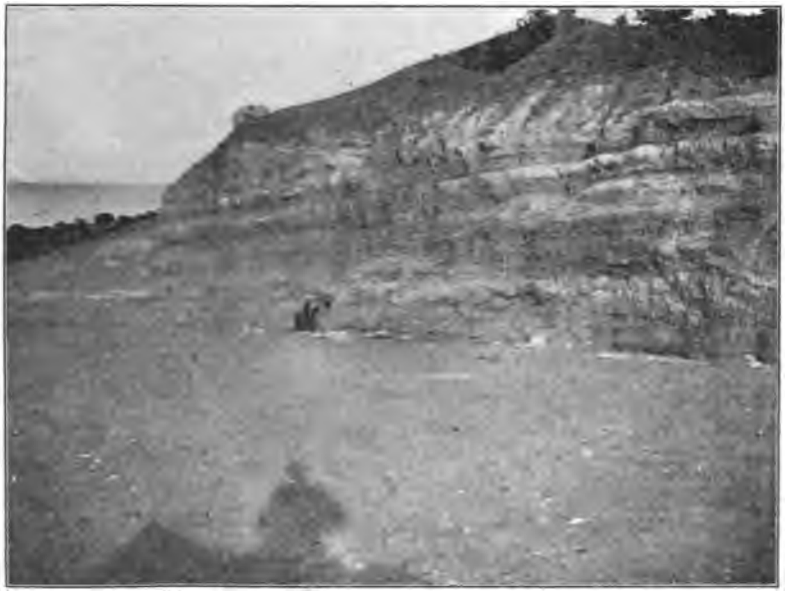

FIG. 2. Santa Fé Marls as exposed in San Marcos Arroyo, east of Cerrillos Hills.

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* Proc. Am. Acad. Arts and Sci., Vol. XXXV., No. 17; pp. 345–373. March, 1900.

that a part of the so-called lake-deposits of Tertiary age are really deposits of the latter nature. Professor Davis described at some length the essential characters of both lacustrine and subaërial deposits, some of which are practically those noted below.

In a large and comparatively deep lake, such as that assumed by the earlier geologists to exist in this region, we should expect the marginal deposits to be more or less coarse and irregular, while the deposits over the central floor of the lake would be of very fine and even texture. That such must be the conditions is shown by the study of existing lakes. No extensive variations in texture or composition would be possible in this central portion. We cannot conceive that either waves or currents could sweep coarse pebbles or boulders far out into such a lake, and so give us layers of conglomerate alternating with fine sands, marls, etc. Such conglomerates could only appear near the shore line. Even coarse sands could not be present alternating with fine marls, etc. As Davis says: " It can hardly be imagined that the sediments deposited on the floor of a large lake should contain frequent alternations of finer and coarser beds, such as clays and sands." On the other hand, in deposits formed by laterally confluent fans of waste, deposited by subaërial agencies, such variations are to be expected. Although in general the coarser débris would be dropped nearer the mouths of the various cañons, and the finer material carried further out, still with the growth of the fans, and the varying conditions due to floods of greater or less extent, changes of season, etc., material of considerable coarseness as well as the finer débris would be carried far out from the mountains. Consequently we should not be surprised to find conglomerates of fair sized pebbles at a considerable distance from the mountains often alternating with fine sands and marls. These variations would be further complicated by the interlocking of different fans laterally, or of fans from different mountain ranges.

In deposits formed on the floor of a large lake we should not expect to find sudden marked variations in the thickness and areal extent of the component beds. This would be especially true of the deposits in the central portion of such a lake, where a considerable degree of uniformity of thickness and extent would necessarily exist. The stratification would be fairly evenly developed, and it would be difficult to conceive of beds of sandstone several feet in thickness suddenly wedging out and disappearing entirely to be replaced by wholly different strata. In alluvial fans, however, such occurrences would be most natural, and while a remarkable degree of perfection in the stratification of the finer deposits of such fans has been noted, instances of the sudden "wedging out" of beds are still more numerous, especially in the coarser deposits. As a necessary corollary, the component layers in lacustrine deposits could vary but little, while those of alluvial deposits might vary greatly, within a limited area.

In lacustrine deposits there would be little or no development of erosion unconformities. It is evident that under normal conditions there would be no opportunity for streams to cut channels in the finer sediments, and then fill these channels with gravel or sand brought from distant sources. In alluvial fans, however, such phenomena would necessarily occur to a greater or less extent. Streams flowing out over the fan, constantly cutting and refilling new channels, and washing boulders and gravel along channels cut in the finest marls or sands, would leave their records in the shape of numerous unconformities of erosion. Such evidence might not always be available, but where it did appear in a marked degree would be undoubted evidence of the subaërial origin of the deposits.

Abundant cross-bedding at high angles would not be expected in deposits on the central portion of a large lake floor, but would be very natural in the sands of alluvial cones, where the changing streams would develop the phenomenon to a marked extent.

A land fauna or flora, with entire absence of fish remains, would be strongly suggestive of a subaërial origin for the deposits enclosing them, rather than a lacustrine origin.

The Cerrillos district occupies a somewhat central position in the area supposed to have been covered by the great Tertiary lake of the earlier geologists. It is at least some ten or fifteen miles from the eastern "shore line" of that lake, and a like distance from the western shore; while to the north and south the lake extended for much greater distances. The small group of the Cerrillos Hills could not have materially affected the deposits of that central area, as they would have been buried beneath the waters of the lake, the deposits occurring elsewhere a number of feet higher than the highest of the Cerrillos peaks. Any other hypothesis would necessitate an extensive subsidence since the deposition of the marls, or varying conditions of depth, of which there is no evidence. In any case, a land area of such limited extent could not affect the deposits over so great an area as the phenomena to be recorded were noted.

Hence, in summing up the criteria upon which we may base our judgment concerning the origin of the Santa Fé Marls of this region, we need only consider the conditions that should prevail near the central portion of such a lake. Briefly, then, if these marls are of lacustrine origin they should exhibit:

1. No great variations in texture and composition in vertical section.
2. No beds of conglomerate.
3. No marked and sudden variations in respect to the thickness and areal extent of the component beds.
4. Few unconformities of erosion.
5. No extensive cross-bedding at high angles.
6. A lacustrine rather than a land fauna or flora.

If, on the other hand, these marls are of alluvial origin, they may exhibit any or all of the above phenomena.

A detailed study of the numerous exposures of the Santa Fé Marls in the Cerrillos region developed the following facts:

1. *The Santa Fé Marls vary greatly in texture and composition in vertical section.* Lying horizontally upon the leveled edges of the upturned Cretaceous strata we most frequently find a bed of peculiar conglomerate or breccia as the basal member of the Marl group. Above it is frequently found a greater or less thickness of very fine, soft marls, with bands of fine-grained sandstones, and coarser layers of pebbles and boulders. All of these variations may be seen in the same vertical section, beds of fairly coarse gravel sometimes capping the finest marls, and in turn being capped by these same fine marls or sands; while good-sized pebbles not infrequently are noted in all the layers.

2. *These Marls contain beds of conglomerate.* As just stated, the basal member of the Marl group in this district is usually a conglomerate of subangular pebbles, cemented by a calcareous cement. In a few places the conglomerate is lacking, while in others a similar bed appears higher in the series.

3. *These Marls show marked and sudden variations in respect to the thickness and areal extent of the component beds.* The peculiar conglomerate so frequently seen as the basal member of these Marls is only 2 or 3 feet thick at the exposures east of Cerrillos; a

quarter of a mile north it is lacking entirely, fine marls resting directly on the upturned Cretaceous beds; a few hundred yards northeast of the last point it reaches a thickness of 20 feet, while a half mile west a thickness of 30 feet is attained. In other localities a variation of from 3 to 30 feet was noted. The same variation was noted in the finer marls and sands. A stratum of pinkish marl a foot thick not infrequently thins out and disappears entirely in a few hundred feet, while a sandstone of the finest texture may grade into a fairly course pudding-stone. If detailed sections were made at every exposure in the district, probably no two such sections would correspond, except in a very general way, so great are the variations exhibited. Comparatively small exposures, seen from a distance, appear beautifully and perfectly stratified. When examined more carefully, or when the attempt is made to trace a given layer any great distance, the true condition is soon made apparent.

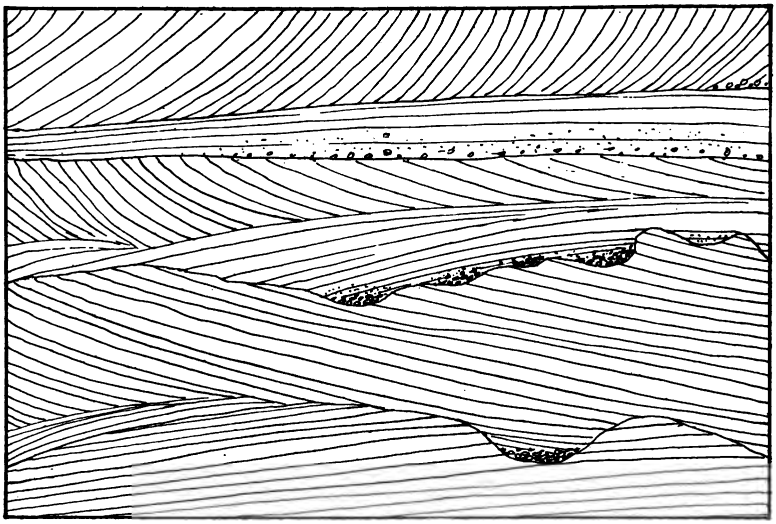

FIG. 3. Diagram Showing Cross-bedding and Unconformities in Santa Fé Marls.

4. *The Marl beds show innumerable unconformities of erosion throughout.* When carefully examined, those exposures which appear the most evenly stratified show numerous and excellent examples of erosion unconformities. The accompanying diagram (Fig. 3) reproduces the conditions noted in a few square feet of the

face of the exposure at the eastern end of San Marcos Arroyo, shown in Fig. 2.

It will be seen that deposition was followed by erosion, then by deposition again, this process being repeated indefinitely. When erosion was progressing, large pebbles were rolled along the little channels, some of which were left to be covered by the fine marl or sand when deposition again took place. In this way pockets of large gravel are found in little hollows cut out of and covered over by the finest of sediments. The small (as well as large) scale upon which these unconformities are developed, and their great number, shows that the time element was not so important a factor as the conditions under which the beds were formed.

5. *These Marls show an extensive development of cross-bedding at high angles.* The foregoing diagram (Fig. 3) also shows the cross-bedding noticed in a small portion of the exposure in San Marcos Arroyo. This cross-bedding, from the lowest to the highest angles (up to 35 or 40 degrees), is characteristic of the deposits at numerous localities in the Cerrillos district.

6. *The fauna of these Marls, as found elsewhere, is essentially a land fauna.* In the Cerrillos district itself no fossils were found in these beds, but Cope describes a land fauna from several places in the same deposits. He himself comments on the utter absence of fish or crocodile remains, and mentions what may be the remains of roots of plants, occurring in a vertical position.

It is also to be noted that all the evidences of a lake shore-line were entirely absent.

The above facts seem conclusive. It is evident that the Santa Fé Marls cannot be of lacustrine origin, but must be the result of subaërial deposition. This conclusion is necessitated not alone by a detailed study of the beds themselves, but also by a general survey of the physiography of the region as a whole. On this basis, indeed, Dr. Tight, in conversation with me, favored the alluvial origin of these beds even before I was convinced of their true relations. One of the most striking features of the country is the beautiful development of the alluvial fans, the materials of which are these Marls. In every direction from each mountain range there spreads out at a low and uniform angle, a gently inclined plain, the low angle gradually decreasing the farther away from the range one goes. This plain inclines away from the range at an angle of from 5° to 6° at the mountains' base, and is seen to be composed of laterally confluent alluvial fans, each fan heading at the mouth of a mountain cañon. Some of these fans, spreading out from the largest cañons of the larger ranges, are seen to be at least ten miles in breadth, by fifteen miles or more from cañon mouth to outer base of the fan. As a rule, however, the individualities of the various fans are soon lost, the whole merging to form a broad, sloping plain.

At the present time these alluvial fans are being dissected by numerous streams and arroyos. This dissection, however, is not well advanced, and the portions of the fans nearer the mountains remain intact, only being cut by the narrow channels of young streams. In some places, indeed, it would seem that aggrading of the fan has not yet entirely ceased, while in others, where erosion has begun to remove the fan, it is evident that the aggradation ceased quite recently, and we find Recent fossils in the upper layers. In fact, when seen from a distance, the fans seem so perfect that it is hard to realize they are not all being built up before one's eyes. The delicate adjustment of the slopes, and the uniform level of those slopes for miles in all directions from a mountain range, certainly indicate a condition but recently reached, and not greatly affected since.

Age.

Concerning the age of the Santa Fé Marls the Cerrillos district offers little evidence. No fossils were found at this locality, and we are forced to rely on data gathered elsewhere. A résumé of the available evidence is given below.

Dr. Hayden, in speaking of these Marls, said:* "To this group I have given the name of Santa Fé marls; and they are doubtless of the age of upper Tertiary, and synchronous with the upper beds of the White River group as seen along the North and South Forks of the Platte and near Cheyenne. * * * I have as yet obtained no well-defined fossils from either the Santa Fé or Arkansas marls; yet bones of some large animal, probably mastodon or elephant, have been found in them."

According to Professor Cope,† Hon. William F. M. Arny, an early governor of New Mexico, was the first to secure vertebrate remains from these Marls. "He obtained from the regions northwest of Santa Fé, the fragments of a lower jaw of a *Mastodon productus* Cope."

The next observations of vertebrate fossils were made by the members of the Wheeler Survey of 1873. Francis Klett and Dr. O. Loew obtained a number of specimens from near San Ildefonso.*

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* Prelim. Field Rep. U. S. Geol. Surv. of Col. and New Mex., 1869, p. 90.

† U. S. Geog. Surv. West of 100th Mer., Vol. IV., Pt. II., p. 24.

In 1874 Professor Cope visited this region, and from the locality near San Ildefonso secured thirty-one species of vertebrates. In discussing "The Loup Fork Beds of the Valley of the Rio Grande," † (the Santa Fé Marls), Professor Cope describes the beds near San Ildefonso, some 25 or 30 miles north of Cerrillos, as being "alternately softer and harder calcareous sandstones and conglomerates, varying from white to greenish gray and light rufous"; and then continues: "They dip generally 10° to 15° toward the east, and away from the basaltic mass of the Jemez (Cochiti) range. They contain the remains of extinct *Vertebrata*, mostly *Mammalia*, which have enabled me to correlate them with the Loup Fork Tertiary of Colorado and Dakota. The species discovered by our party number thirty-two, of which twenty-six are Mammals, three Birds and two Reptiles." In his paper entitled "Notes on the Santa Fé Marls and Some of the Contained Vetebrate Fossils" ‡ Professor Cope speaks of the presence in these beds of "the genera *Hippotherium*, *Protohippus*, *Procamelus*, *Cosoryx*, *Merychyus*, and known Pliocene species of other genera, among which may be mentioned *Canis*, *Aceratherium*, etc." A number of new species were also established, and descriptions appended.

While on this same expedition Professor Cope visited the northern end of the Sandia Mountains, and examined the marls or clays, some 40 feet in thickness, which occupy the intervals between low hills of "Cretaceous No. 3," near the village of Placitas. He says: § "I obtained teeth and other bones of *Elephas primigenius* subspecies *columbi* from this bed, and found bones of Elephants in place in the banks of the arroyo. Shells of *Planorbis*, *Physa*, etc., indicte the lacustrine character of the deposit which I have called the Placita marls." On the basis of the above fauna Professor Cope refers these beds to the post-Pliocene epoch. As will appear below, I am convinced of their identity with a part of the Santa Fé Marls.

An extinct vulturine bird || was reported from these Marls near

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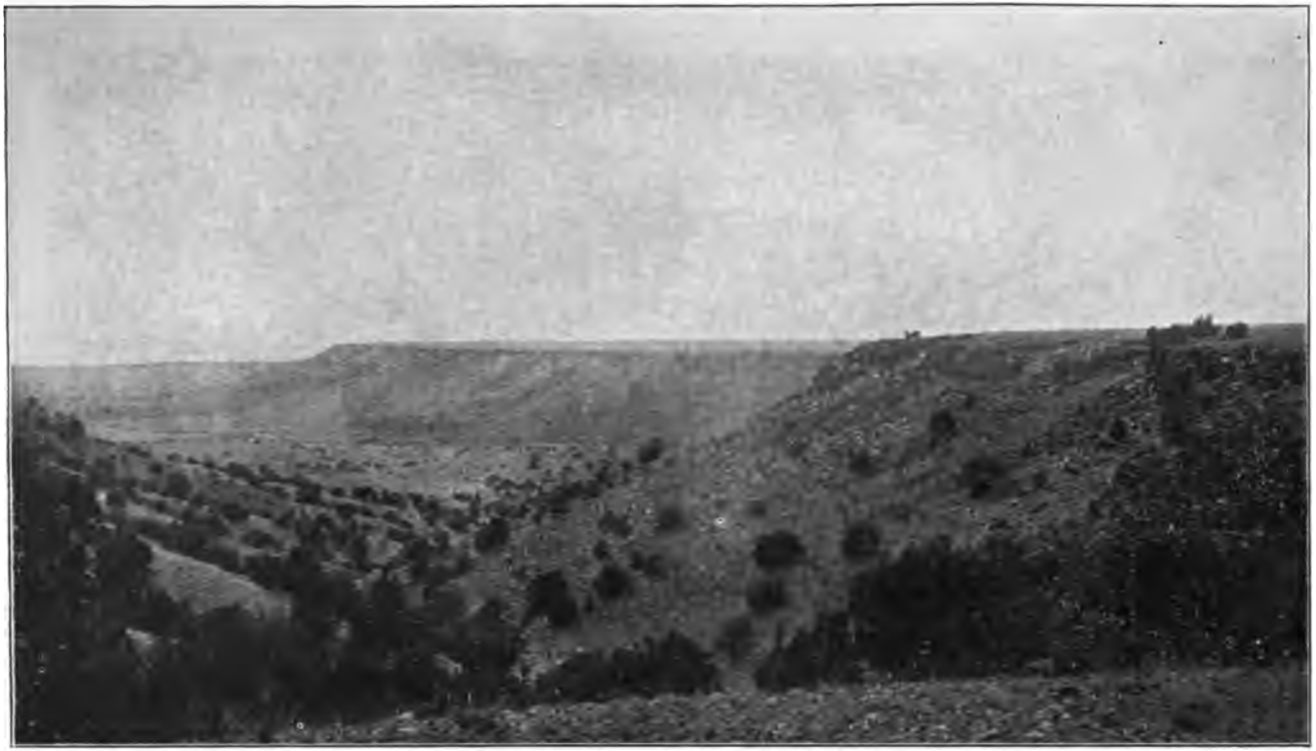
* *Loc. cit.*

† *Ibid.*, pp. 20–25.

‡ *Proc. Phil. Acad. Nat. Sci.*, 1874, pp. 147–152, pls. IX–XI.

§ U. S. Geog. Surv. West of 100th Mer., Vol. VI., Pt. II., p. 25.

|| *Proc. Phil. Acad. Nat. Sci.*, 1875, p. 271.



BASALT FLOW CAPPING SANTA FÉ MARLS. (West of Cerrillos Hills.)

Santa Fé, and described as *Cathartes umbrosus* Cope. Further examination showed it to belong to the vulturine division of Falconidæ, and the name was changed to *Vultur umbrosus*.

From near Santa Cruz Professor Cope reports * the bones of *Mastodon* and *Aceratherium jemezanum* Cope, in beds referred to the Santa Fé Marls.

Professor Stevenson reports no fossils from the Cerrillos region, but says,† regarding the age of his so-called Galisteo group, which we have seen to be identical with the Santa Fé Marls: "Whether the Galisteo group belongs to the Miocene or the early Pliocene could not be determined. * * * It cannot be older than early Miocene or newer than early Pliocene." Regarding the upper part of these Marls, which part alone he calls Santa Fé Marls, Professor Stevenson merely states that "Professor Cope has determined that the Santa Fé Marls belong to the Loup River epoch of the Pliocene."

Within the last year or two Dr. W. G. Tight, of the University of New Mexico, has found the skeleton of an elk and some freshwater shells near the southern end of the Sandia Mountains, in beds which he considers identical with those in the Cerrillos district.

In summing up the evidence we cannot doubt the Loup Fork age of a part of these beds, at least. Even if we were to assume that the beds at San Ildefonso were not identical with the true Santa Fé Marls, the remains of *Mastodon productus* and *Vultur umbrosus*, from the typical locality of these Marls, would be sufficient proof of their Loup Fork age. At the same time I do not believe anyone who visits the several localities can doubt for a moment but that the Placitas marls at the north end of the Sandia Mountains, and the deposits studied by Dr. Tight at the south end of the same range, are parts of great alluvial fans closely identical with those forming the Santa Fé Marls further north and east. Nor do I believe they could doubt the recent age of a portion, at least, of these Marls as shown in the typical locality. But the Placitas marls contain a post-Pliocene fauna, while Dr. Tight finds an elk in the beds at the southern end of the Sandias.

There is only one explanation, and that a very reasonable one, that will account for the above conditions. We may well believe that these great alluvial fans were forming in the Loup Fork epoch, and so entombed the remains of the fauna that roamed over them at that time. These fans, with possibly more or less interruption, have continued to form until recent time. In the more recent portions of these deposits were entombed the remains of post-Pliocene faunas. It is possible that these fans may have been greatly eroded at times, and subsequently built up again, due to varying geologic conditions. If such were the case, it would be well-nigh impossible to detect it in beds of this nature, where erosion unconformities and frequent alternations of beds of varying texture and composition are frequent even where deposition is practically continuous.

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* U. S. Geog. Surv. West of 100th Mer., Vol. IV., Pt. II., p. 23.

† U. S. Geog. Surv. West of 100th Mer., Vol. III., Supplement, p. 162.

So while the Santa Fé Marls represent a period extending from the Loup Fork epoch to the present time, I do not believe it possible to subdivide the beds, or to recognize the different stages represented, except where fossils are immediately present.

Although these fans are now being dissected in places, and rivers and arroyos have cut out narrow valleys in them, I have seen local instances of aggradation on their surfaces. Bones of cattle and horses have become partially buried by the fine silt that may be seen washing out over the inclined plane during any heavy shower, thus giving a demonstration of the processes that were at work when the bones of the *Mastodon* were being entombed in Tertiary times.

THE GALISTEO SAND GROUP.

Laramie (?).

Along the eastern border of the Cerrillos district the Galisteo Creek and its tributary arroyos have removed the Santa Fé Marls, revealing a series of easterly dipping red sandstones which Hayden has named the Galisteo Group. The beds of this series are mainly deep brick red or purplish-red sands, sandstones and marly sand, with occasional bands of a yellow or white color. So far as known this group contains no fossils except the silicified trunks of trees. These occur in great numbers at a point a few miles east of Cerrillos, and give the locality its name, the "petrified forest." As a rule the tree trunks are found weathered out in large pieces, but a number were seen lying horizontally imbedded in the sands.

The close resemblance of these beds to those of the "Red Beds" proper, of Jura-Triassic or Permian age, has led to no little confusion, as will be apparent on reading the literature summarized below. The marked contrast between these beds and the yellow sandstones immediately below, has led me to adopt the contact between the two as the division line between the Galisteo Group of Hayden and the series for which I propose the name Madrid Group. In thus placing the lower limit of the Galisteo Group at the base of the red sandstone series I believe I am following exactly the limit implied, though not directly stated, by Hayden. As noted near the close of this section, there is an additional argument for this location of the limit in the evidence of a marked change at this point in the physical conditions attending deposition.

A résumé of the literature bearing on the Galisteo Group, together with the conclusions of the various writers, is given below.

In July, 1846, Dr. Wislizenus visited the gold region south of the Galisteo, crossed the creek near Cerrillos, and wrote*: "Ascending afterwards to the hills, I met everywhere with a red and brown sandstone, looser or more compact, and with large masses of petrified wood."

In September of the same year Lieutenant Abert made a trip from Santa Fé to the gold mines in the Ortiz Mountains. In describing the journey, he says: † "Toward the latter part of the day we entered a very sandy country; here lay huge masses of sandstone and fragments of immense petrified trees."

In both of the above cases I have little doubt but that the "petrified forest" in the Galisteo Group is referred to.

In the fall of 1853 Jules Marcou visited the Cerrillos region, and referred the Cretaceous rocks farther east to the Jurassic and Triassic. It does not appear from his notes,‡ however, that he studied the Galisteo Group proper, as has been thought by some.

On his second visit to this region, in 1859, Professor Newberry noted that the rocks exposed in the valley of the Galisteo consisted of portions of the Triassic, Cretaceous and Tertiary, and said that the Triassic rocks contained great numbers of silicified trunks of coniferous trees.§

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* Senate Miscellaneous Document No. 26, 30th Congress, 1st Session, p. 29.

† Senate Executive Document No. 23, 30th Congress, 1st Session, pp. 32–33.

‡ Expl. and Surv. for a R. R. route from Miss. Riv. to Pac. Ocean, Vol. III., Pt. IV., No. 2, pp. 140–141.

§ Rep. of the Expl. Exped. from Santa Fé, N. M., to the Junc. of Grand and Green Riv., 1859, Geol. Rep., pp. 38–42.

In 1867 Dr. Le Conte visited the region and in his report* mentions "probable Trias" near Galisteo Creek containing great quantities of silicified wood.

In 1869 Dr. Hayden made a trip from Santa Fé to the Ortiz Mountains, at which time he described and named the Galisteo Group. He says: † "As we descend the hill into the valley of the Galisteo Creek, we have a wonderful exhibition of the variegated sands and sandstones, which at first appear like the upper series of red beds on the east side of the mountains, but which I at once suspected were new to me in this region. * * *

"Passing up the Galisteo, eastward, we observed the variegated sands and sandstones, rising above the coal strata, and concealing them on the northeast and east flanks of the Placiére Mountain, inclining at all angles from five degrees to fifty degrees. These sandstones are of varied texture, from a fine aggregate of quartz particles to a rather coarse pudding-stone. In some of the beds there are irregular layers, of a dull, rusty brown, concretionary arenaceous limestone, in which I searched in vain for fossils. One of the most peculiar features of these beds, and one which I have never seen in any group before, is the great variety of colors, from a light reddish tint to a deep brick red, sometimes dull purplish light, and very deep yellow, white, brown, drab, etc. The only fossils I could find were enormous silicified trunks of trees. * * * I have named these beds the Galisteo sand group, as they are confined, so far as I know at present, to the valley of the Galisteo, although they pass under the Santa Fé marls, and the northern limit is concealed from view."

Dr. Hayden clearly states his idea of the age of this group, as well as its relations to the underlying and overlying rocks, in the following words: "We have, therefore, in the valley of the Rio Grande, if my investigations are correct, three groups of tertiary beds of different ages. (1) The coal strata, with abundant impressions of deciduous leaves, lying above well-marked Cretaceous beds. (2) The Galisteo sand group, which plainly overlies the coal strata, but inclines equally with and conforms to them. (3) The Santa Fé marls, which are of much later date than either of the other two, and rest unconformably upon the Galisteo group, and never incline more than five or ten degrees."

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* Notes on Geol. of Surv. for the Extension of Union Pac. R. R., Phila., 1868, pp. 36–41.

† Prelim. Field Rep. U. S. Geol. Surv. of Col. and New Mex., 1869, pp. 66–68.

In 1874 Dr. Loew visited this district and in his report stated * that "between the Placer Mountains and Santa Fé we cross several valleys of erosion, in which the Triassic beds with their characteristic fossil wood are well exposed."

In the same year Professor Cope visited the region, and according to his statement, studied the Galisteo Group, both in the valley of the Galisteo and on the eastern flank of the Sandia Mountains. He says: † "The age of the Galisteo sandstone is a point not satisfactorily decided. So far as their position on the flanks of the Sandia Mountains indicates, they may belong anywhere from Cretaceous No. 3 to the Coal Measures. That they are not of Tertiary age, as has been supposed by some, is clear. Dr. Hayden's observations lead to the conclusion that they are not older than the Cretaceous, since he states that they overlie the coal of Placer Mountain, which itself is superior in position to undoubted Cretaceous beds. If these positions be correct, this group constitutes a special member of the Cretaceous formations." A careful study of Professor Cope's description of the beds, ‡ and of the position of his route through this region, has convinced me that the beds visited and described by him in the Galisteo valley were the "Red Beds" proper, of Permian of Jura-Triassic age, exposed at the base of the Galisteo monocline, several miles west of the exposures of the Galisteo Group. The fact that he did not see the coal is further proof of the error. There is no evidence to show that he ever saw the Galisteo Group itself. The beds seen by him on the flank of the Sandias are doubtless the same as those he mistook for the Galisteo Group, and lie below the Cretaceous and immediately upon Upper Carboniferous limestone. The lithologic similarity of the Red Beds proper and the red sandstones of the Galisteo Group, together with the fact that their strike and dip, and relations to the overlying Santa Fé Marls are all identical, probably led to the error.

In 1875 Professor Stevenson, in commenting on Dr. Hayden's description of these beds, said: § "A careful comparison of this section as given by Dr. Hayden, with the details of the geology along Dr. Newberry's route from Santa Fé westward, as given in

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* Rep. of Chief of Engineers, 1875, Pt. II., p. 1028.

† *Ibid.*, p. 997.

‡ *Ibid.*, p. 996.

§ *Proc. Am. Phil. Soc.*, Vol. 14, 1875, p. 462.

Ives' report, will, I think, satisfy everybody that Dr. Hayden has by some oversight inverted the order, and that the Galisteo group *underlies* the coal group. The Galisteo group is unquestionably the Triassic, as abundantly appears from the descriptions of that system in New Mexico, by Newberry and Le Conte."

Later in the same year Professor Cope quoted the above criticism of Stevenson's and replied * to it by saying that his own study of the region convinced him that the Galisteo Group rested upon the coal group, as stated by Dr. Hayden. The resemblance of this group to the Triassic he regarded as accidental. As we have just seen, however, Professor Cope did not have the true Galisteo Group in mind.

In 1878 Professor Stevenson visited the region, and gave an extensive account of the geology in his report † to Lieut. G. M. Wheeler. In this report he considers the Galisteo Group of Hayden ‡ to be a part of the Laramie or coal formation, and recognizes its true position above the coal.§

In 1898 Dr. Herrick published a brief account of the geology of the Cerrillos district || in which he referred to Cretaceous sandstones east of the town of Cerrillos containing abundant silicified trunks of trees. That he later considered these beds of Jura-Triassic age appears in a paper on the "Geological Associations in New Mexico Mining Camps,"¶ in which he attributes the origin of the turquoise to metamorphism of these red sandstones by the intruded lava. In a note to the writer, he refers other inclusions of red sandstones, seen further east, to the Jura-Triassic. All inclusions of red sandstone in that locality belong to the Galisteo Group.

When I began my study of this series I was impressed with the close lithologic resemblance of these beds to those of the Red Beds proper, and noting several faults parallel to the strike in these beds themselves, was led to adopt the idea of such a fault between the

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* *Proc. Phila. Acad. Sci.*, 1875, p. 360.

† U. S. Geog. Surv. West of 100th Mer., Vol. III., Supplement, 1881.

‡ In this connection it must be borne in mind that the extensive description of "The Galisteo Group" given in Professor Stevenson's report does not apply to the true Galisteo Group of Hayden, but to the Santa Fé Marls of that author. Professor Stevenson considered the true Galisteo Group under the head of his "Laramie."

§ *Ibid.*, pp. 159, 160, etc.

|| *Bull. Univ. New Mexico*, Vol. I., pp. 109–114.

¶ Rep. of the Governor of N. Mex. to the Secretary of the Interior, for 1900, pp. 257–260.

red sandstones and the light yellow series just west as a working hypothesis, thus regarding this red series as a faulted-up portion of the Jura-Trias or Permian. A very careful study of several good exposures of the contact of these two series failed to reveal any evidence of a fault. The occurrence, in the valley east of Cerrillos, of the red sandstones standing vertical, and at the same time parallel to the yellow sandstones of the coal or Madrid Group, showed that the theory of a fault must be abandoned.

Thinking the fossil tree trunks might throw some light on the question, I submitted thin sections to Mr. Frank H. Knowlton. He found that they indicated a tree unknown in the Red Beds proper, but of evident Upper Cretaceous or later affinities. In a letter to me on the subject, he said: "The wood is a dicotyledon, and while it has been somewhat distorted by fossilization, it appears to be a species of *Quercus*. In any event it shows a highly organized dicotyledonous tree, wholly unlike anything known from the Jura-Trias, and might well belong to the Upper Cretaceous or later."

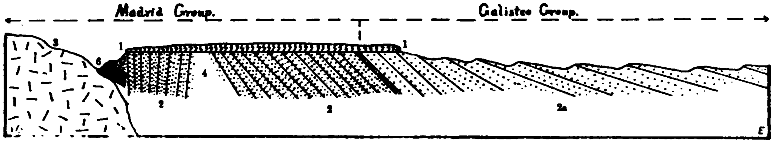

FIG. 4. Section east of Cerrillos; 1, Santa Fé Marls; 2, sandstones; *2a*, red sands of Galisteo Group; 3, intrusive andesite (laccolith); 4, concealed; 6, carbonaceous shales.

Both stratigraphic and palæontologic evidence thus proving the more recent age of these beds, it is possible to arrive at a fairly accurate idea concerning their relations. The coal seams at Madrid are but a few feet above undoubted Upper Fort Pierre beds. As we shall see, both the stratigraphic position and the fossil leaves indicate the Fox Hills age of the coal. Conformable upon the coal are over a thousand feet of massive yellow sands, whose upper member is a 25-foot band of very white sandstone. As will be seen elsewhere, I include this series with the coal beds, and give the name Madrid Group to the whole, considering this group to be of Fox Hills age.

Immediately above the white sandstone band at the top of the Madrid group, the deep red sands of the Galisteo Group are found. The contrast with the underlying Madrid Group is very marked.

Evidently a marked change in the physical conditions attended the inauguration of this new series. It may be that this change was in some way connected with the coming in of the Laramie epoch, and that the Galisteo Group is of Laramie age.

The upper limit of these beds was not seen, but it may well be doubted if anything higher than Laramie is represented. Previous to the accumulation of the Loup Fork deposits of the Santa Fé Marls there was a vast period during which the region was elevated and worn down to a peneplain, reëlevated, and again subjected to erosion. It is not unreasonable to suppose that this erosion period dated back to or near the close of Laramie time, the great upheaval which tilted and elevated these beds being the same which inaugurated Tertiary conditions. This uplift resulted in much faulting of the beds, so that it was impossible to arrive at any satisfactory opinion regarding their thickness. Along several of these great strike faults the beds on the down-faulted side are turned up until they stand vertical, giving beautiful illustrations of this common result of such displacements. There are at least between 1,500 and 2,000 feet of these deposits, while the thickness may possibly be greater.

That we have typical "Red Beds" of late Cretaceous or Laramie age is clearly shown, and the danger of placing too much dependence upon lithologic similarity again illustrated. That this point needs to be emphasized especially in connection with the "Red Beds" of the West is soon apparent on reading the geological literature of regions where these beds are well developed. The tendency to regard all the Red Beds as belonging to the Jura Triassic or Permian is marked. It was on this basis that Professor Stevenson regarded the Galisteo group as "unquestionably Triassic." In a paper above referred to Dr. C. L. Herrick says: "The Jura-Triassic sandstones are widely distributed and are easily recognized by the red color." This same idea has been shared by others, and in my own case led to a wholly wrong assumption as a working hypothesis.

THE MADRID COAL GROUP.

Fox Hills.

The arroyos tributary to the Galisteo on the south side of that creek have removed the Santa Fé Marls from a considerable area south of the town of Cerrillos, revealing a series of easterly dipping yellow and white sandstones, over a thousand feet in thickness. The lower 300 feet of this series contain several coal seams of workable thickness, together with some shale beds. The upper portion of the series consists almost wholly of massive yellow and white sands. To this series I propose to give the name "Madrid Group." The coal seams outcrop at the town of Madrid, and the region is known as the Madrid coal field.

It is difficult to arrive at an accurate estimate of the thickness of these beds. In the Madrid field several extensive and numerous smaller interstra sheets of the intrusive occur. The Madrid section (Fig. 5) shows between 200 and 300 feet of the lower portion of this Madrid Group, together with several of these intrusive sheets. The upper portion of this group is best exposed on the north side of the creek, a mile or two east of Cerrillos (Fig. 4). Here the yellow and white sandstones are upturned by the Cerrillos intrusion and the Santa Fé Marls deposited upon their planed-off edges (see plate G). There are several faults shown in the section, but in one place 850 feet of the massive sands were traced without a break. A study of the section will make it apparent that even when due allowance is made for the faults, a much greater thickness of sediments is represented. It is probable that the whole of the Madrid Group, as indicated by the Madrid section and the section east of Cerrillos, comprises anywhere from 1,500 to 2,000 feet of strata. The relations in the field indicated that

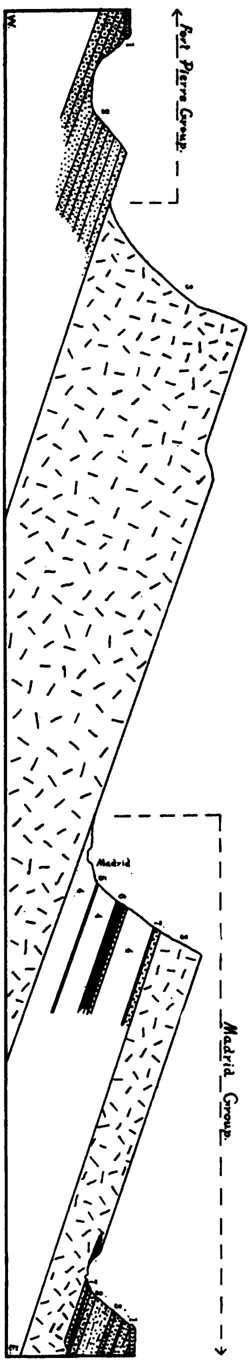

Fig. 5. Madrid Section: 1, Santa Fé Marls ; 2, sandstones ; 3, intrusive andesite ; 4, concealed ; 5, bituminous coal ; 6, lignitic shales ; 7, anthracite.

the lowest bed in the section east of Cerrillos, of carbonaceous shales, belonged somewhere near the upper part of the Madrid section. It is not probable that any notable thickness of beds has been omitted, nor that any duplication has occurred, in thus correlating the two sections.

The coal in the lower portion of the Madrid Group has proven of great interest to geologists, and so many references have been made to it in the literature that it would be almost impossible to secure them all. It is of interest, however, to 'note the observations of the earlier explorers and the conclusions arrived at by several geologists regarding the age and origin of the anthracite bed — the upper workable seam in the region.

In 1846 Lieut. Abert stated* that he found evidence of coal on one of the tributaries of Galisteo Creek.

In 1857 Professor Blake visited the Cerrillos region and published "Observations on the Geology of the Rocky Mountain Chain in the Vicinity of Santa Fé, New Mexico."† He mentioned the anthracite coal of the Madrid field, and provisionally referred the beds to the Carboniferous. Similar notes were published elsewhere.‡

During his first visit to this general region in 1858, Professor Newberry secured samples of the anthracite coal from Mr. Mercure in Santa Fé, but was unable to visit the locality from which they came.§ In 1859, however, Professor Newberry again visited the region, and studied the coal beds of the Madrid Group. He recorded ‖ the occurrence of lignite in Cretaceous on both sides of the Galisteo Creek, and noted that on the south side of the creek an "outburst and overflow of trap" had changed the lignite into good anthracite coal.

In 1867 Dr. Le Conte studied the geology of this region.¶ He speaks of the anthracite bed in the Madrid Group as "a coal bed, which by the overflow of a lava stream, now congealed into gray prophyry, has been converted into a substance resembling anthracite, but much lighter and more brittle than the anthracites of the older formations." Dr. Le Conte then gives a detailed section of a portion of these beds, and refers them to the lower Cretaceous in the following words: "From the proximity of the marl series, the absence of all characteristic upper and middle Cretaceous shells, and the known existence of lower Cretaceous lignites west of the Rio Grande, I infer that the anthracite beds belong to that period."

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*Senate Executive Document, No. 25, p. 37.

† *Proc. A. A. A. S.*, 1859, pp. 314–319.

‡ *Proc. Boston Soc. Nat. Hist.*, 1859, pp. 64–70.

§ Rep. upon Colo. Riv. of the West, J. C. Rives, Wash., 1861; Pt. III., pp. 98–99.

‖ Rep. Expl. Exped. from Santa Fe, N. M., to Junc. of Green and Grand Riv., 1859; Geol. Rep., pp. 38–42.

¶ Notes on Geol. of Surv. for Extension of Union Pac. R. R., Phila., 1868, pp 36–41.

In 1869 Dr. Hayden studied these beds, and wrote about them as follows:* "The outcroppings of coal on the northwest side of the Placiére Mountains are of great interest. They were first exposed in the center of the little branches that run into the Galisteo. The first one is about five miles south of the Galisteo. The coal is in the natural condition.

"* * * At another locality there is a bed of coal, which has been changed by an enormous dike into anthracite. (Then follows section of beds.) The dip of all the beds is fourteen degrees east. They are overlaid by a thick bed of columnar basalt. The dike that covers the coal bed trends about north and south, or a little east of south." Dr. Hayden mentions the occurrence of abundant impressions of deciduous leaves with the first coal bed mentioned, and refers the whole of the coal group to the Tertiary.

In 1874 Professor Cope visited the region, and according to Professor Stevenson † placed these coals in Cretaceous No. 3. As stated elsewhere (p. 335), I am not able to find that Professor Cope ever visited this immediate locality, and his references to the position of the coal were made upon a mistaken idea of the identity of the Galisteo Group.

In the same year Dr. Loew visited the region, mentioned ‡ the occurrence of the seams of coal in the arroyo south of Cerrillos, and gave several analyses § of the anthracite. Dr. Loew says: ‖ "The coal is probably of Carboniferous age."

In 1878 Professor Stevenson made a study of the geology of this locality, and in his report described ¶ the coal series at some length, giving detailed sections. Professor Stevenson refers this group to the Laramie.

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* Prelim. Field Rep. U. S. Geol. Surv. of Col. and New Mex., pp. 67, 68.

† U. S. Geog. Surv. West of 100th Mer., Vol. III., Supplement, p. 35.

‡ Rep. of Chief of Engineers, 1875, Part II., p. 1028.

§ U. S. Geog. Surv. West of 100th Mer., Vol. III., pp. 632, 634.

‖ *Ibid.*, p. 633.

¶ U. S. Geog. Surv. West of 100th Mer., Vol. III., Supplement, pp. 126–130.

In 1895 Professor Stevenson again visited the Cerrillos region, and made a more detailed study of the Madrid Group. His conclusions * deal more especially with the nature, occurrence and origin of the anthracite, and are considered elsewhere in this report. The geological relations are described in some detail, however, the beds being referred, as before, to the Laramie. Regarding the Fox Hills Professor Stevenson says: † "The Fox Hills stage of the Rocky Mountains region is not represented in this area."

In 1898 Dr. Herrick studied the Ortiz and Cerrillos region, and in his published notes ‡ briefly describes the coal series and refers it to the Cretaceous, no more definite a reference being made.

In the summer of 1899 and 1900 I made several short excursions into this region and on stratigraphic grounds was led to refer this Madrid Group to the Fox Hills. The more detailed work of the summer of 1902 has served to confirm the former reference.

Further west, in the valley of the Rio Puerco, are exposed a series of lignite beds, above which are massive yellow standstones similar to those of the Cerrillos region. In these yellow sandstones I found abundant fragments of sharks' teeth and a few marine shells. On the basis of shells and leaves which he collected here, Dr. C. L. Herrick referred these beds to the Fox Hills.

In the Madrid region about 100 feet below the lowest coal bed are abundant marine fossils of Upper Fort Pierre age.§ From 1,500 to 2,000 feet above the coal of the Madrid Group, in the Galisteo Group which overlies it conformably, are silicified tree trunks of Upper Cretaceous or later affinities. In the Madrid Group itself are found fossil leaves, one species of which is only known from the Fox Hills, while another is only known from beds of doubtful, but probable Fox Hills, age. In view of these facts, and since lignites in other parts of the Territory are known to be of Fox Hills age, I have no hesitation in referring the Madrid Group to that period.

The details of the Madrid Group are shown in the following sec-

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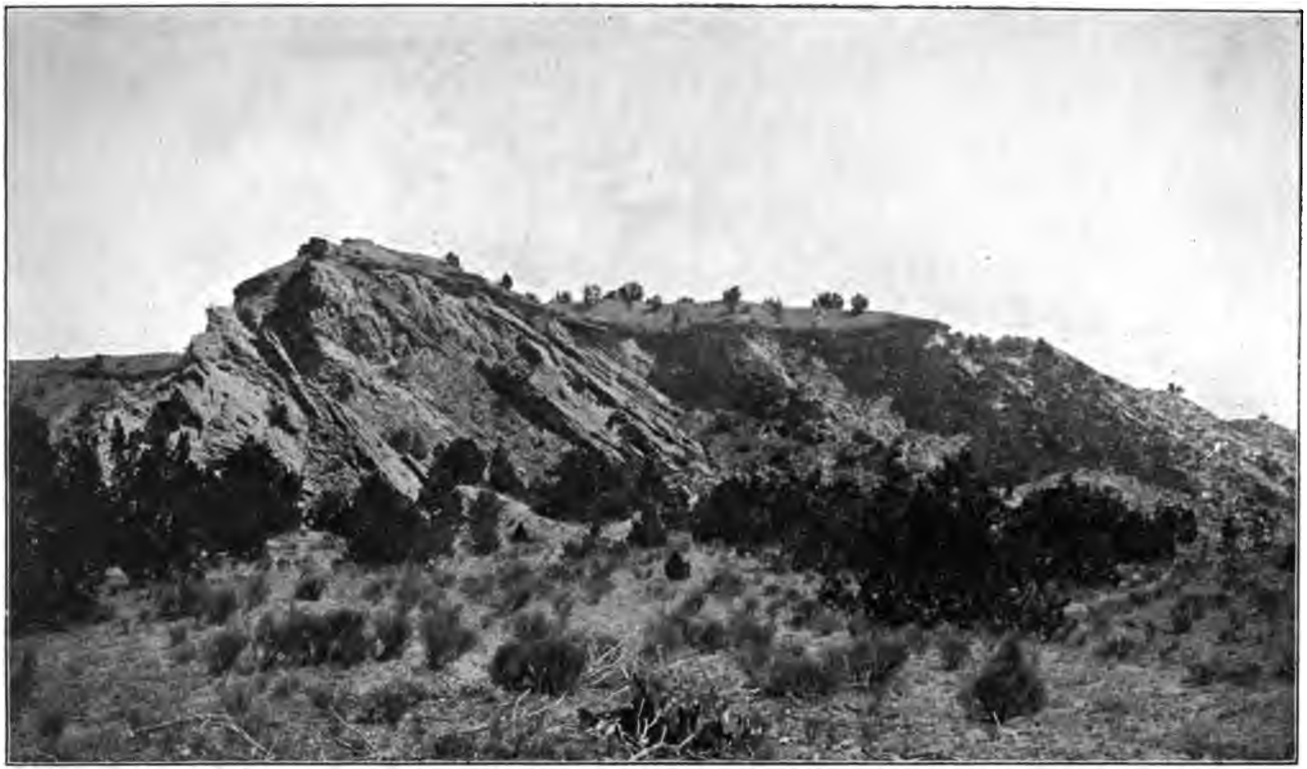
* *Trans. N. Y. Acad Sci.*, Jan., 1896, pp. 105–122.

† *Ibid.*, p. 111.

‡ *Bull. Univ. New Mex.*, Vol. I., pp. 109–114.

§ See Part II., Palaeontology, of this report.



Sandstones of Madrid Group, Capped by Horizontal Santa Fé Marls. (East of Cerrillos.)

tion, compiled from the lower part of the section east of Cerrillos (Fig. 4) and the upper part of the Madrid section (Fig. 5). Minor coal seams occur in some of the shale beds, but were not visible in the sections. The beds are given in descending order:

	Feet.
Massive white sandstone	25
Marly sands	Few
Massive yellow sands with occasional loose, marly bands	850
Concealed (loose marly sands? with possible fault)	175
Massive and loose shaly sands	350
Loose yellow sands	150
Fault.	
Loose yellow sands	100
White sandstone	15
Carbonaceous shales	50

Continued in the upper part of the Madrid section as follows:

	Feet.
Loose sand (upper part concealed)	Several
Intruded lava sheet	1
Soft sandstone	8
Intruded lava sheet	3
Soft sandstone	10
More indurated sandstone (fossil leaves)	9
Carbonaceous shales	10
Sandstones	6
Intruded lava sheet	8–10
Shales	3–4
Coal seam	2
Shales	3
Concealed	Few
Intruded lava sheet (west to Madrid)	65
Concealed (probably lava sheet)	65
Sandstone	1
Shales and coal (anthracite)	3
Sandstone	7
Shales	2
Coal (anthracite)	3
Shales	2
Concealed	100
Sandstone	16
Lignitic shales	30
Concealed	70
Coal (bituminous)	3
Concealed (sandstone and carbonaceous shales in well boring)	100 +
Intruded lava sheet	Several hundred

As will be seen from the above, 30 feet of carbonaceous shales containing considerable brown lignite are exposed in the Madrid escarpment near the mines, occurring 125 feet below the anthracite, and 70 feet above the bituminous coal. In a section a little over 200 feet in vertical extent we thus have all of the three important stages in the production of anthracite represented. The significance of this in connection with the origin of the anthracite is emphasized elsewhere. The fossil leaves, belonging to the species *Ficus uncata* Lesquereux, *Ficus rhamnoides* Knowlton, and *Aralia*? sp., were found in the 9-foot band of sandstone above the coal exposed half a mile east of Madrid, and are described and figured in Part II., Palæontology, of this report. The petrographic description of the interstrata sheets of lava occurs in Part III., Petrography. That these lava sheets were intruded between the beds is shown by the metamorphic effects both above and below the lava, by the fact that the sheets send off tongues of lava into the overlying beds, and by the deep-seated character of the intruded material. In the Madrid area these interstrata flows doubtless connected with, and had their origin in, the great Ortiz laccolith to the south.

THE FORT PIERRE GROUP.

Since the Fort Pierre shales and sandstones are found mainly along the western side of the Cerrillos district, away from the usual line of travel to the coal and placer mines, and contain nothing of special economic interest, they do not play as important a part in the literature of this region as do the groups previously discussed. It is true that in the reports of several of the earlier geologists references are made to fossils collected and other data secured from Cretaceous beds in this region, some of which references may apply to the beds of this group. But in all cases the statements are very general, or there is considerable doubt as to the beds actually under consideration.

In 1869 Dr. Hayden noted* "the dark shales of No. 4, apparently." In 1878 Professor Stevenson made a study of the region, and gave more exact descriptions of this formation.† He recorded the presence of Fort Pierre shales on the south and west sides of the Cerrillos Hills, where they were said to contain fragments of huge *Inocerami* and other fossils, and beds of iron ore. The great distortion of the beds is referred to.

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* Prelim. Field Rep. U. S. Geol. Surv. of Colorado and New Mexico, 1869, p. 67.

† U. S. Geog. Surv. West of 100th Mer., Vol. III., Supplement, pp. 99–101, 329, etc.

The Fort Pierre Group in the Cerrillos region consists of beds of dark arenaceous shales, shaly and massive sandstones, and loose sands. These beds are quite fossiliferous in places, and their fauna is described in Part II., Palæontology, of this report. So far as the greatly disturbed and faulted condition of the beds would permit one to determine, the upper part of the group consists largely of the sandstones and shaly sands, while the lower, and probably greater, portion consists of dark arenaceous shales. In the Achavica Arroyo section (Fig. 6) 170 feet of these sands were measured, while 160 feet appear in the Madrid section (Fig. 5). It was impossible to get any idea of the thickness of the shales below. The whole area of the low broad vale west of the Cerrillos Hills and north of the Galisteo Creek, except a narrow band along its western edge, is largely composed of these dark gray or drab shale beds. But the area is cut by a large series of intersecting dikes, faults are numerous and of unknown extent, and the beds are up-tilted, overthrown, and twisted in every conceivable manner. In one place several hundred feet of these shales appear dipping westward away from the Cerrillos uplift, but minor faults were certainly present, and more extensive ones may have been. There is little doubt but that a considerable thickness is represented, however, the whole of the Fort Pierre Group probably reaching the thickness of over 1,000 feet given by Stevenson for this group in other localities.

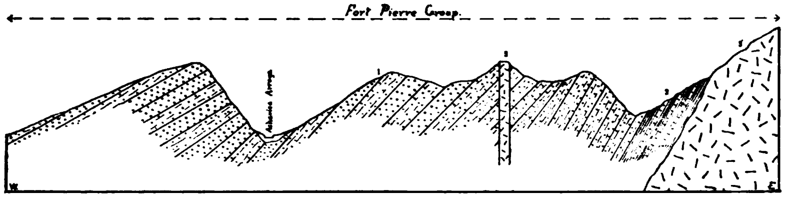

FIG. 6. Achavica Arroyo Section.— 1, Sandstones. 2, Sands and shales. 3, Intrusive andesite (laccolith and dyke).

The detailed character of the upper sandy portion of the Fort Pierre Group may better be appreciated by a study of the typical sections, which are here repeated. The Madrid section (Fig. 5) was made along a nearly east and west line passing through the town of Madrid, and was about a mile and a half in length. This section shows an easterly dipping series of sandstones and shales, with several intrusive sheets of lava. At the base of this section, about a mile west of Madrid, are found beds of yellow and white sands, overlain by one of the intrusive sheets, as follows:

	Feet.
Intruded sheet of lava.	
Massive sandstone	30
Shaly "	6
Massive "	6
Shaly "	40
Shaly sandstone with concretions	30
(Small hiatus.)	
Loose sands with concretions	50

The lower eighty feet of this section were fossiliferous, the fossils gathered being mostly weathered out, probably from the concretions, and were of Fort Pierre age.

The Achavica Arroyo section (Fig. 6) was made one mile northwest of Grand Central Mountain, in Achavica Arroyo, where are exposed a series of sandstones and shales, dipping sharply away from the intrusive core of the main uplift, with which these beds are in contact at the eastern end of the section. At the western end the section is terminated by a fault, beyond which the beds dip toward the east, apparently away from a smaller intrusion of the lava a few rods farther west. The whole formation is considerably metamorphosed, and the strike and dip vary greatly, the average being about N. 40 E. for the former and 50 W. for the latter. The following beds are exposed, given in descending order:

[Fault cutting off section at western end (top)].

	Feet.
A. Sandstones and shaly sands	60
B. Sandstones and shaly sands	40
Small dike.	
C. Shaly sands	40
D. Shaly sands	
E. Sandstones and shaly sands	30
F. Mostly shales	20
Intrusive core of main uplift.	

A few fossils were found in each of the above divisions, and showed the Fort Pierre age of the beds.

In both of the above sections several new species of fossils were secured, and are described, together with the rest of the forms, in Part II. of this report. In each case enough well-known forms were present to leave no doubt as to the age of the deposits.

Good Fort Pierre fossils were also found in the lower dark shales in several places, but no satisfactory sections could be obtained.

Layers of nodular iron ore have been mentioned from these beds by several writers, some of whom attached considerable importance to the occurrence. No beds of value have been developed, nor did I see any indications of notable quantities of iron in the region.

THE NIOBRARA GROUP.

Dr. Hayden speaks* of finding "the full series of the Cretaceous beds" in this locality. His more definite description is as follows:† "A great thickness of Cretaceous shales No. 2, passing up into laminated arenaceous shales, with fossils, then the dark shales of No. 4, apparently." No specific mention of Cretaceous No. 3, or the Niobrara Group, is made.

Professor Stevenson says:‡ "The limestones only of this group were seen on Galisteo Creek, where the exposures are far from being complete." He doubtless referred to the region about Galisteo, some sixteen miles further east, as he elsewhere § mentions the occurrence of small exposures of this group at that locality.

In the Cerrillos region itself I found no beds of undoubted Niobrara age, nor any limestones resembling those of this group. Just north of the town of Cerrillos is a small and imperfect exposure of Fort Benton shales, but it did not appear that anything belonging to the Niobrara was represented there. At the top of the Galisteo Monocline were found beds containing *Ostrea lugubris* Conrad, and which may belong to the Niobrara, although lithologically they more closely resemble the Fort Benton. It is also possible that some of the beds below the known Fort Pierre on the south side of the creek may belong to the Niobrara.

THE FORT BENTON GROUP.

Dr. Hayden speaks || of "a great thickness of Cretaceous shales No. 2" west of the Cerrillos Hills. It seems probable that the most of this "great thickness" of shales belongs to the Fort Pierre,

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* Prelim. Field Rep. U. S. Geol. Surv. of Col. and New Mex., 1869, p. 66.

† *Ibid.*, p. 67.

‡ U. S. Geog. Surv. West of 100th Mer., Vol. III., Supplement, p. 98.

§ *Ibid.*, p. 340.

|| Prelim. Field Rep. U. S. Geol. Surv. of Col. and New Mex., 1869, p. 67.

although the Fort Benton is represented. Professor Stevenson does not mention this group as occurring in the Cerrillos district, although he records* it from fifteen or twenty miles farther east.

The exposures of the Fort Benton group in the Cerrillos district are few, small and imperfect, but one such exposure gives undoubted faunal proof of its age. Just north of the town of Cerrillos, almost in contact with the intrusive mass of the main Cerrillos uplift is exposed a small bed of dark calcareous shales, striking N. 45 W. and dipping 25 N., or in toward the intrusive. This represents one of the groups of strata which are found in close proximity to the laccolith, dipping in toward it, the beds generally dipping away from the uplift in all directions. From these shales a characteristic Fort Benton fauna was collected, as noted in Part II. of this report. The shales are not well shown, but apparently are of but limited areal extent.

Several miles west of Cerrillos, just south of the main wagon road west, are exposed easterly dipping shales which form the most eastern exposure of the Galisteo Monocline. About one hundred feet of these shales are shown between interstrata sheets of lava, and from them a number of specimens of *Ostrea lugubris* Conrad, a fossil characteristic of the Colorado formation, were collected. These shales may possibly belong to the Niobrara, although lithologically they more closely resemble the Fort Benton.

Judging from the small and imperfect exposures of this group one might be led to suspect that it did not attain a very great thickness in this region. Professor Stevenson reports† that in other localities the exposures of this group are seldom good, and assigns a thickness of rarely more than 150 feet to it.

THE DAKOTA GROUP.

Professor Stevenson does not report the Dakota formation from the Cerrillos region, although he mentions it as occurring in the vicinity of Galisteo a number of miles farther east. If present in the Cerrillos district at all, it is only exposed as a narrow band in the Galisteo Monocline, at the western border of the district. Dr. C. L. Herrick gives‡ the following section of the monocline at a point a little north of the creek — beds given in descending order:

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*U. S. Geog. Surv. West of 100th Mer., Vol. III., Supplement, p. 97.

† *Ibid.*, p. 96.

‡ *Bull. Univ. New Mex.*, Vol. I., p. 109.

	Feet.
Sandstone with conglomerate	25
Sands and shales	30
White sandstone	3+
White sandy shales	20
White sandstone	3
Chocolate shales with concretions	75
White sandstone	175
Massive red sandstone	75*
Red shales and sands	50

The red beds at the base are doubtless the typical "Red Beds" of probable Jura-Triassic age. East of this section, and above the uppermost beds here given, are the dark gray shales with typical fossils of Colorado age. It seems not improbable, then, that the upper part of the above section, with possibly still higher beds, belongs to the Dakota Group, although definite proof is lacking.

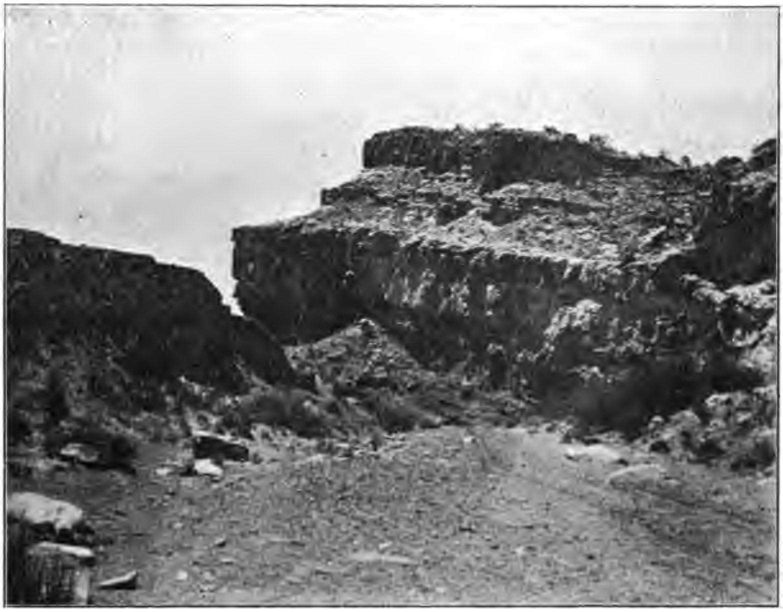

FIG. 7. Jura-Triassic (?) Red Beds, base of Galisteo Monocline.

JURA-TRIAS (?).

The lowest beds exposed in the Cerrillos region are found at the base of the Galisteo Monocline (see foregoing section), where are exposed 125 feet of red sandstones and shales below fossiliferous Cretaceous beds. These doubtless belong to the typical "Red Beds," and were correctly correlated by Cope with the Red Beds exposed above the Upper Carboniferous on the eastern flank of the Sandia Mountains. These beds doubtless represent what we have of the Permian and Jura-Triassic in the region, and it would not seem unwarrantable to correlate this lower part of the Galisteo Monocline section with the Jura-Trias, since the upper part only of the "Red Beds" are here represented. I am not able to present any faunal evidence in support of the correlation.

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* Thickness not given in Dr. Herrick's section, but supplied by writer.

To be Continued.

PART I. GENERAL GEOLOGY.

(*Continued.*)

AREAL GEOLOGY.

On the geological map accompanying this report I have endeavored to represent the areal geology with as fair a degree of accuracy as the nature of the base maps would permit. As previously stated, the topography indicated by the contour lines does not accurately represent the relations of the true topography to the geology. It will be seen however, that the Santa Fé Marls occupy a large portion of the area north and south of the Galisteo Creek, while the underlying Cretaceous beds are exposed only where the creek and its tributary arroyos have removed these marls. West of the hills there is a broad, open vale where the marls have been stripped off almost entirely, giving the most extensive exposures of the Cretaceous in the region.

Except where the laccolithic intrusions of the Cerrillos Hills have disturbed them, the beds older than the Santa Fé Marls all dip uniformly to the east at an angle of from 15 to 20 degrees. Thus in passing from the western edge of the area to the eastern limit, we have a geological section beginning with the top of the Jura Triassic (?) red beds at the base, and passing up through the Cretaceous to the upper portion of the red sandstones of the Galisteo Group (Larimie ?). Unfortunately, this section is greatly broken along the Galisteo Creek, where the best exposures are to be found, by the laccolithic intrusions of the Cerrillos Hills. Farther to the south, where the beds are less disturbed, the horizontal covering of Santa F Marls conceals them, and exposures are only found in the valleys and arroyos.

The movement which produced this uniform eastward dip was probably the same which resulted in the great monoclinal uplift of the Sandia Mountains some thirty miles to the southwest. Throughout the whole region east and west of the Sandia range, for thirty miles or more in either direction, there is a notably uniform dip to the eastward, except where local uplifts have affected the sediments in their immediate vicinities. To the south this uplift is pronounced in the Manzano and more southern ranges, which are continuations of the Sandia range. For this great movement I propose the name of "Sandia uplift." It has been noted by some of the earlier geological explorers and in the geological section from the Mississippi River to the Pacific Ocean, prepared by Wm. P. Blake from the notes of Jules Marcou,* it is represented as culminating in the Sandia Mountains.

This uplift has resulted in a series of great north and south fractures. Twenty-five miles west of the Sandias the Cretaceous is faulted up against later beds along a north-and-south break which was traced for thirty or forty miles. Nearer the range, a series of recent volcanic cones occurs along a north-and-south line, doubtless marking an extensive north-and-south fracture. The Sandias themselves, together with their southern extensions, mark a great north-and-south fault which had a throw of over four thousand feet in places. Less conspicuous, but quite extensive north-and-south faults occur at other points throughout the general region.

In view of the above facts it is interesting to note that the groups of laccolithic mountains of which the Cerrillos Hills form the northernmost member, are arranged along a nearly north-and-south line. The rocks composing them are of the same general character, as shown by the study of thin sections, while their mode of occurrence is similar. It seems not unlikely, then, that the Cerrillos, Ortiz, San Pedro and South Mountains occur along one of the great north-and-south fractures, which fracture served to release the andesitic lava confined below. The fracture died out before reaching the surface, so that the rising molten lava spread laterally, and arched up the overlying beds, forming great laccolithic intrusions. In each case the overarching beds have been largely removed, but the highly inclined strata around the intrusive reveal the nature of the uplift. For convenience I shall speak of the several laccolithic intrusions forming the Cerrillos Hills as the "Cerrillos intrusion."

With this understanding of the two main movements which have materially affected the position of the sediments, we can trace

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* Pacific Railroad Reports, Vol. III., Plate.

CRATER HILL. (Low basalt crater northwest of the Cerrillos Hills.)

out the areal distribution of the beds more intelligently. If, then, we start at the western edge of the sheet and follow southeastward up the valley of the Galisteo Creek, we begin with the easterly-dipping red sandstones and shales of the Jura-Triassic (?) series (Fig. 7). We soon reach the limit of this series and encounter the yellow and white sandstones referred doubtfully to the Dakota group of the Cretaceous. A short distance still farther east are dark shales of undoubted Colorado age. From here to the western edge of the Cerrillos Hills, a distance of two miles, perhaps, the whole area is occupied by dark shales and thin beds of sandstones, which have been tilted and faulted by the Cerrillos uplift. Fort Pierre fossils were found at several localities throughout this area. Along the western base of the hills the beds dip westward, away from the uplift (Fig. 6), but farther south the eastward dip continues.

As we pass on eastward along the southern base of the hills, we find that here the beds dip sharply to the south, away from the uplift, while further south the eastward dip remains unchanged. The beds are of Fort Pierre age. Close to the base of the hills Fort Benton strata are brought up to view by the laccolith, while farther south Fox Hills beds are encountered.

Farther eastward we pass up into strata of the Madrid Group, of Fox Hills age. These beds are well exposed in Ortiz Arroyo, and further south as far west as Madrid and Rogers, where they dip a little north of east, and contain the coal seams of economic importance. A mile east of Cerrillos they are turned up vertical by one of the smaller laccolithic masses, and then dip more gradually eastward as we pass away from the uplift (Plate G and Fig. 4).

East of the Madrid Group we find the red sandstones of the Galisteo Group, of Laramie (?) age, which have the usual easterly dip except on the north side of the creek near the intrusives, where in places they are turned up quite sharply. Eastward, however, where the "petrified forest" is found, the effect of the Cerrillos intrusion has died out entirely, and the dip to the east is quite uniform throughout the whole area (Fig. 4). Under the influence of the intrusion the contact of this Galisteo Group with the underlying Madrid Group swings sharply eastward from a point just southeast of the town of Cerrillos, so that the red sandstones are found much farther west on the south side of the creek than on the north. The same is true of the Madrid Group, which is found as far west as Rogers on the south side.

The ideal section, Fig. 8, shows the conditions above referred to, with all minor disturbances of the beds ignored. The actual sections, given in connection with the map, represent the conditions more accurately, as found in two representative sections across the area.

To recapitulate: The Jura-Triassic (?) and Cretaceous beds, exposed over the central and southern portions of the map, dip eastward under the influence of the great Sandia uplift, but are tilted in all directions close to the Cerrillos Hills under the influence of the local Cerrillos intrusions. The horizontal deposits of the Santa Fé Marls cover the northern and southern portions of the map, where they have not been eroded by the Galisteo Creek and its tributaries. It is to be noted that remnants of these Marls still remain, capping little mesas out in the valleys which the streams have carved. They are also found as little ledges adhering to the sides of arroyos carved in the hard rock of the Cerrillos Hills, in exposures extremely numerous, but too small to appear on the map.

The Cerrillos Hills themselves are shown on the map to occupy a somewhat central position in the area, their low, rolling foothills extending some distance east of the main peaks. These peaks, as well as the whole western portion of the intrusion, consists of rocks of the augite-andesite series, the several phases of which are discussed in Part III., Petrography. The low foothills to the east are of hornblende-andesite, this rock covering an area of two or three square miles. The smaller outlying hills to the northeast are of the augite-andesite rocks. In many places, both in the main hills and the smaller outliers, the andesite has been sheared and altered so that it appears white or yellow, in strong contrast with the dark gray of the fresh material. It is in these altered bands, which are quite extensive in places, that the turquoise deposits

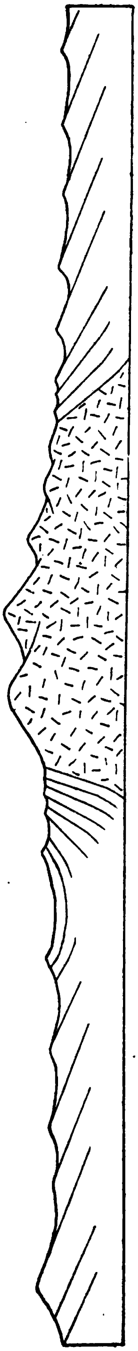


Fig. 8. Ideal east-and-west section through the Cerrillos Hills.

of Mt. Chalchihuitl and Turquoise Hill occur. Mineralized belts mark others of these sheared zones. A more detailed discussion of the hills is given in connection with the consideration of their origin.

Northwest of the hills is the low basalt crater (Plate H) from which a thin flow of olivine basalt has spread out over the Santa Fé Marls (Plate F), covering several square miles of territory. The erosion which has exposed the Cretaceous in the low vale west of the hills has removed a little of the southern part of this basalt sheet, as well as the Marls immediately beneath it. The flow at this point is only 12 or 15 feet in thickness, and is notably vesicular. The rock is quite black in color, while near the crater it is a dull red, from abundant iron stain. It would seem that the surface of the Marls over which it flowed was fairly level, no marked unconformities of erosion being seen. The flow extends a little westward beyond the limits of the map, while to the north it merges with other similar flows, through which the Santa Fé Creek cuts its way. Northeast of the volcano the conical hill known as Mt. Calvary (Plate I) is shown on the northern edge of the map. This hill is composed of the feldspar free basalt, limburgite. Just east of it is another of the outlying hills of augite andesite.

At the western base of Mt. Calvary, and one mile east of Grand Central Mountain, are small exposures of the volcanic breccia which occurs interstratified with the red sandstones of the Galisteo Group, just east of the eastern border of the map (Plate J). At that point the breccia is shown to be over a hundred feet in thickness, with occasional lenses of red sand, indicating the intermittent action of the explosive volcano from which the material came. This breccia is well stratified, showing the effects of the sorting action of water. It rests on red sandstone containing silicified fragments of tree trunks. The petrographical discussion occurs in Part III. of this report.

In the southern part of the area are shown small areas of rocks of the hornblende-andesite series. These represent intruded sheets or sills of the andesite, which have their origin in the laccolithic Ortiz Mountains to the south, and dip east with the Cretaceous beds in which they occur (Fig. 5). Similar sills of the augite andesite are found at several places along the south and west sides of the hills, where they dip away from the uplift, together with the beds in which they occur.

Radiating outward from the Cerrillos Hills is a beautiful system of dykes, some of which extend across the country for several miles as high walls. These are best shown in the vale west of the hills, where they are cut by a later series of basalt dykes radiating from the volcano to the north. In Ortiz Arroyo, south of the town of Cerrillos, one of the andesite dykes (Fig. 9) is well exposed, standing as a narrow wall fifty feet or more above the valley floor This dyke is faulted several feet in an east-and-west direction, allowing the arroyo to cut through the narrow gateway thus formed. The "Madrid dyke" (Fig. 10), running north and south through Coal Gulch, seems to come from the Ortiz rather than the Cerrillos Group, since it grows steadily narrower to the north, and finally disappears entirely. The andesite dykes never cut the Santa Fé Marls, being older than they. Several basalt dykes south of the hills have a trend which suggests for them another origin than the volcano, as noted in subsequent pages.

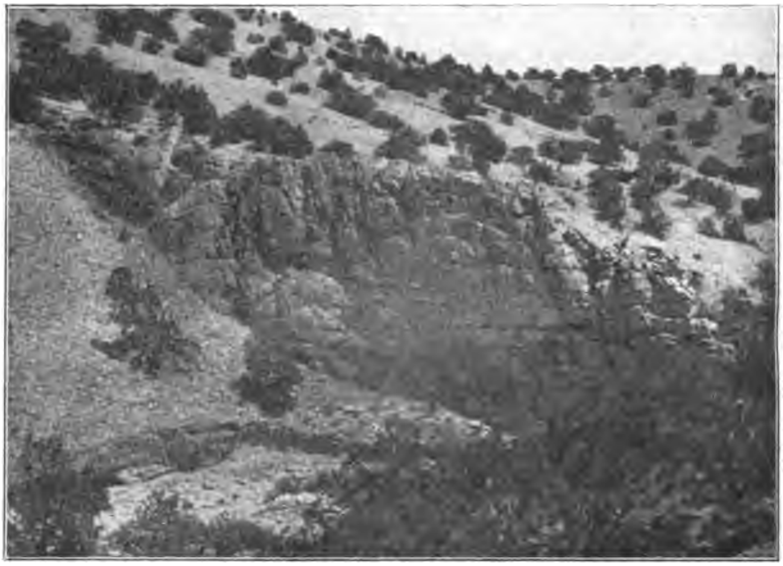
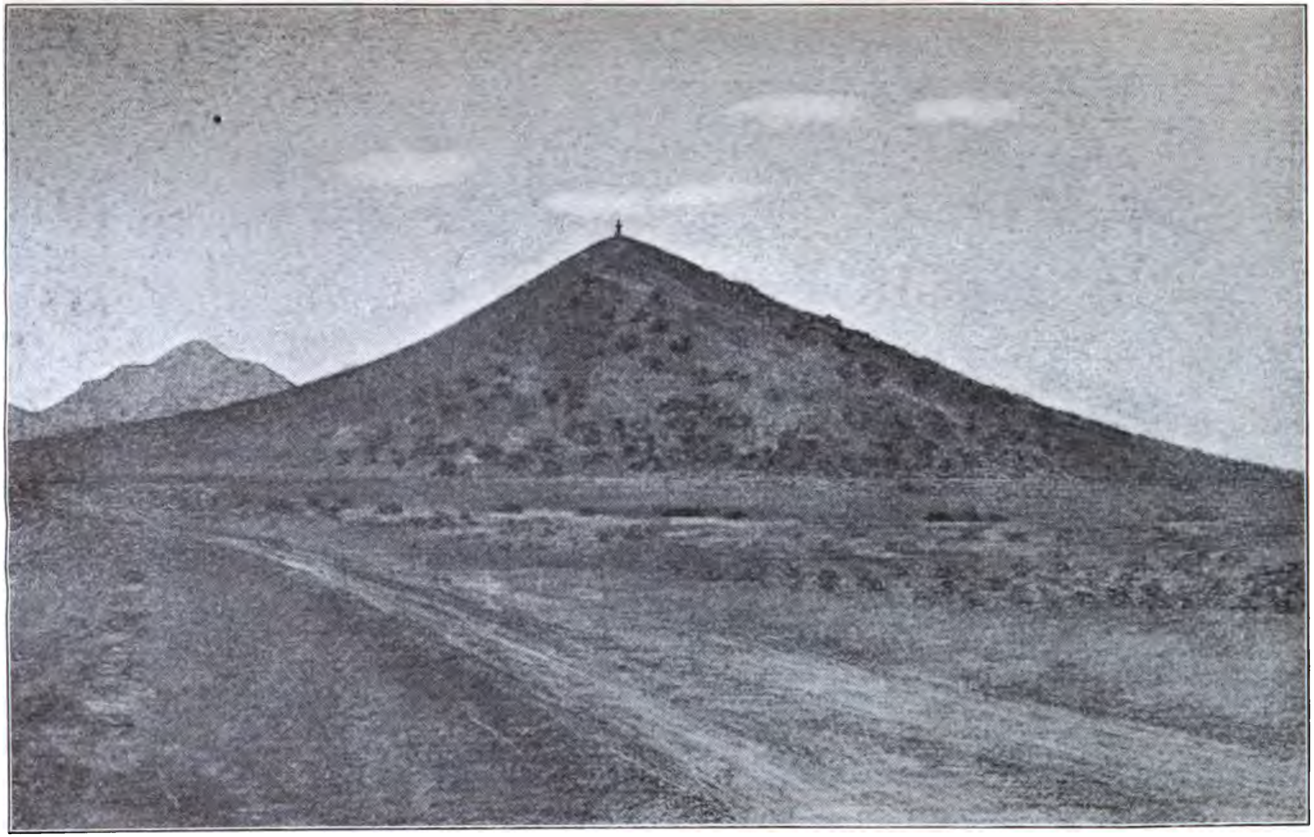


FIG. 9. Dyke south of Cerrillos.

Several small exposures of interstratified sheets of mica andesite are found south and west of the hills. One of these occurs in the Galisteo Monocline, the easterly dipping beds near the western edge of the area. Immediately above it are fossiliferous shales of



MOUNT CALVARY. (Conical hill of basalt north of the Cerrillos Hills.)

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Colorado age. Another of these sheets is shown northeast of Waldo, dipping sharply away from the laccolith with the shales in which it occurs. Farther east, north of Cerrillos, shales of Colorado (Fort Benton) age are found near the laccolith. A third exposure of the andesite occurs along the road two miles and a half northwest of Waldo, in dark shales similar to those found at the two other localities. The resemblance of the rock in all three cases suggests that they are parts of the same sheet, and hence that some portion of the Colorado shales are brought to the surface at the point northwest of Waldo, in the vale where most of the shales are apparently of Fort Pierre age. The disturbed condition of the beds, and the nature of the country, prevent accurate stratigraphic determinations. As noted in the petrographic description of this mica andesite, it appears that the rock was vesicular, and was poured out as a surface flow over beds of Colorado age, being subsequently buried, greatly altered, and finally uptilted by the Sandia and Cerrillos uplifts along with the beds in which it occurs.

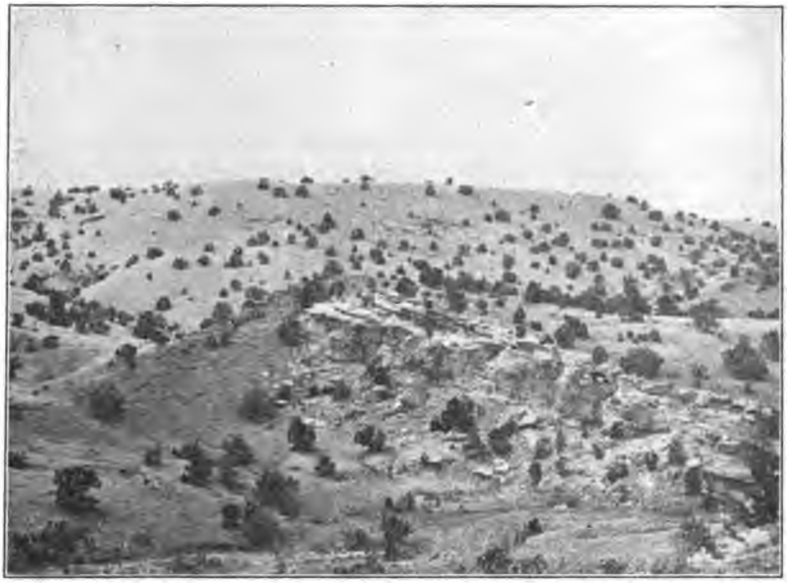


FIG. 10. "Madrid dyke" cutting sandstones of the Madrid Group, in Coal Gulch.

Near the top of the Galisteo Monocline there occurs a small intruded sheet of the augite andesite, which may be an offshoot from one of the dykes. The rock of this sheet shows some peculiar mineralogical variations, as noted in Part III.

Having now briefly sketched the more salient features of the areal geology, a consideration of the nature of the Cerrillos intrusion is presented, after which the subsequent physiographic history of the region will be discussed. We will then be in a position to review the main events in the whole geologic history of the region, so far as available records make this possible.

ORIGIN OF THE CERRILLOS HILLS.

The Cerrillos Hills have been considered by some geologists as remnants of great dykes, and by others as remnants of old volcanoes, from which the flow and more or less of the cone have been eroded. So far as I am aware a laccolithic origin has never been suggested. This is not surprising when we consider the comparative youth of the laccolithic idea, the obscure relations which the Cerrillos Hills present, and the fact that the work of the earlier geologists was necessarily in the nature of brief reconnoissances.

Since the classic work of Gilbert on the Henry Mountains, laccolithic mountains have been described from a number of localities in the West. The work of Cross, Weed and Pirsson, Jaggar and others has established the importance of this type of mountain form, and given us a good conception of its peculiar characteristics. The study of the Cerrillos Hills leaves little doubt as to their laccolithic origin, and in the following paragraphs I shall endeavor to point out the features which convinced me of their identity in structure with laccolithic intrusions elsewhere described.

As evidence of the intrusive nature of the Henry Mountains, Gilbert pointed out the following facts, which may be applied as tests to any uplift supposedly of laccolithic origin: (1) No fragments of the eruptive are found in the associated strata; (2) the eruptive is never vesicular or fragmental, as in surface flows; (3) the inclination of the strata at high angles proves that they were tilted subsequent to their deposition; (4) sheets cut across the strata, and so must be subsequent to their deposition; (5) contact phenomena occur in the beds above, as well as those below, the laccoliths. In addition to the above, we may note the following features which are also more especially characteristic of laccolithic intrusions: (1) The dipping away of the strata in all, or many, directions from the intrusive. This may not occur on all sides of a laccolith, as pointed out in the case of several asymmetrical laccoliths which have been carefully studied; or the evidence may be wholly wanting as a result of advanced erosion; or, as is the case in parts of the Cerrillos region, it may be wholly obscured by being covered with later sediments. (2) The occurrence of intrusive sheets, especially thick near the laccolith, dipping away from it at more or less high angles, together with the strata in which they occur. These are the sheets which fill in the hollows of the bending strata near the base of the laccolith. Intrusive sheets may also occur in all other positions about the laccolith. (3) The presence of annular drainage (sometimes inherited in the hard rock of the laccolith itself). These features may be absent, but when present are valuable evidence in favor of a laccolithic origin.

In the Cerrillos region the laccolithic origin of the hills is not shown with the diagrammatic clearness that is found in some groups of similar origin. It is probable that the Sandia uplift occurred previous to the Cerrillos uplift, and that the laccolithic masses were intruded in the inclined strata. As has been shown by Cross and others, this results in more or less irregularity of form. It also appears from the evidence available that part of the Cerrillos laccoliths were intruded before the rest, which is another cause of irregularity in form. Erosion has removed all of the sediments from the hills and has greatly dissected the intrusive rock. Thus the evidence of over-arching sediments is lacking. At the same time, erosion has not cut deep enough to reveal good exposures of the base of the intrusives.

Subsequent to this erosion the great alluvial fans of the Santa Fé Marls spread out over the region and completely buried everything except the peaks of the hills themselves, wholly obscuring all traces of the upturned sediments and other evidences of the true nature of the uplift. More recent erosion has removed these marls from the southern base of the hills, but the whole northern portion still lies buried beneath this mantle, the conical peaks rising abruptly from the plain.

In view of these facts it is not strange that earlier geologists, giving to these hills but limited study, should regard them as remnants of great dykes or surface volcanoes. When studied in more detail, however, they offer the following evidences of their laccolithic origin:

1. In the case of the Cerrillos Hills, no fragments of the eruptive are found in the associated strata. This statement does not apply to the Santa Fé Marls, of course, which are of much more recent age, of alluvial origin, and which may therefore be ignored in this discussion.

2. In no case is the rock vesicular or fragmental. On the contrary it is a hard, dense rock, compactly crystalline, almost granitoid in places, and showing every evidence of having cooled in depth under pressure. (See Part III., Petrography, of this report, under the Hornblende-Andesite and Augite-Andesite Series.)

3. The strata dip away from the hills at high angles, thus proving tilting subsequent to deposition. In several places near the intrusive the beds are almost vertical, while east of Cerillos they are even pushed back beyond the vertical. (See Figs. 4 and 6 and Plate G. Also sections on map.)

4. In a few localities sheets were seen to send out tongues of the lava into the adjacent beds, thus proving their intrusive nature. One such case is well shown in Achavica Arroyo, west of Grand Central Mountain.

5. Contact phenomena were noted in the beds which rested upturned against the laccolith. Sandstones were hardened to quartzites, while shales and their contained fossils were profoundly metamorphosed. In places the shales were baked to very dense hornstone, as near the locality mentioned above.

6. Wherever exposed, the beds dip in all directions away from the laccolith. The only exceptions to this case are found in a few small exposures, which represent small blocks faulted into abnormal positions, or caught up in the mass of the intrusive itself. Apparent abnormal dips on the east side of the hills are shown to be due to small subordinate laccoliths. This dip away from the intrusive is best shown south of the hills, where the Galisteo Creek has cut the best section through the critical points. Here the strata in contact with the intrusive dip south at an angle of from 70° to 80°. On the south bank of the creek the dip changes to 65°, 50° and 40°, finally dying out until the beds resume their usual easterly dip.

7. Intrusive sheets, especially thick and dipping away at high angles near the uplift, thinner and less steeply inclined farther away are found in several localities throughout the region. Some of the best of these are shown along the creek between Cerrillos

and Waldo. Here one great sheet occurs in Cretaceous shales which dip 80° to the south, or away from the laccolith (see Plate K). The soft shales have been so greatly eroded from about it that it stands up like part of a huge east and west dyke. Just south are several thinner sheets, dipping at angles from 65° to 40°. The accompanying diagram (Fig. 11) will serve to illustrate the conditions there represented.

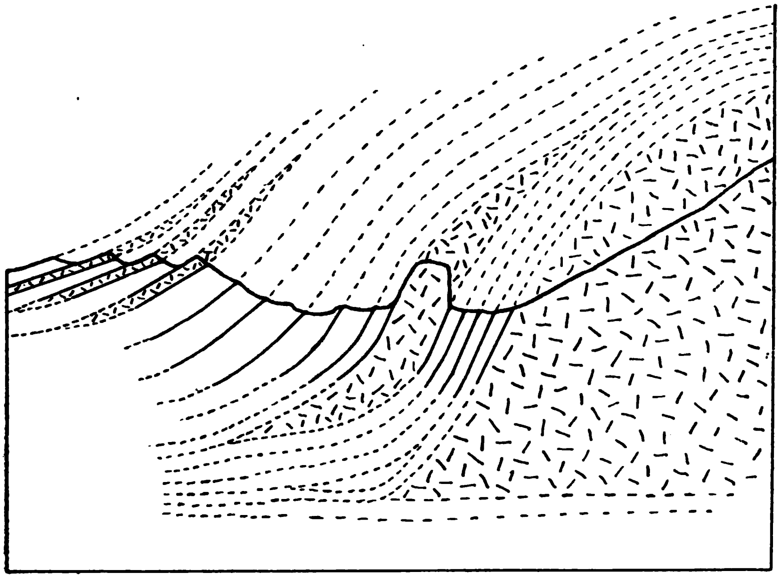


FIG. 11. Diagram illustrating relations of intrusive sheets west of Cerrillos.

Another such intruded sheet, similar to the larger one above described, is seen as a great wall east of Cerrillos. The shales are here nearly vertical. Smaller sheets of this nature are found in a number of places throughout the region. The large sheets of the Madrid area have their origin in the Ortiz Mountains, farther south, and occur in beds which have been but little disturbed from their easterly dip. It is possible that they have their origin in dykes, as is apparently the case with some small sheets in the area west of the hills.

8. There is some evidence of inheritance of annular drainage from valleys in previously domed sediments. San Marcos Arroyo follows around the eastern and southeastern side of the hills, and, as can be seen from the contour lines, is contin-

ued around toward the northwest in a low depression, to a point northeast of Turquoise Hill. From Cerrillos, where San Marcos Arroyo joins the Galisteo Creek, the drainage is to the northwest, while Achavica Arroyo, rising between two of the main laccoliths, flows down the western side of the hills. This drainage was established prior to the formation of the Santa Fé Marls, as shown in subsequent pages. A considerable portion of San Marcos Arroyo is in the hard rock of the laccolithic mass itself. And even where the arroyo seems to follow near the contact of the sediments and the laccolith, it has cut narrow gorges through offshoots of the main mass. Such a case of inherited drainage is shown in Fig. 12, where the arroyo cuts through a short, thick ridge of the andesite, although lower and more easily eroded country is found a few rods both north and south of the gorge.

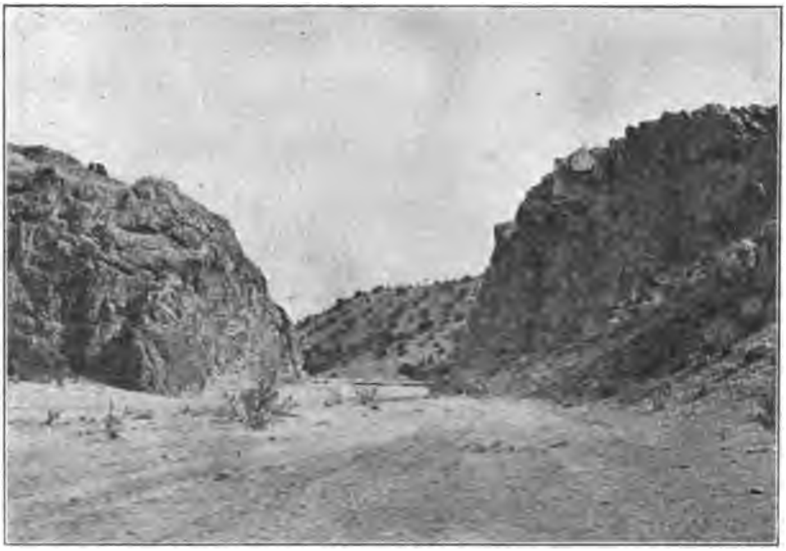
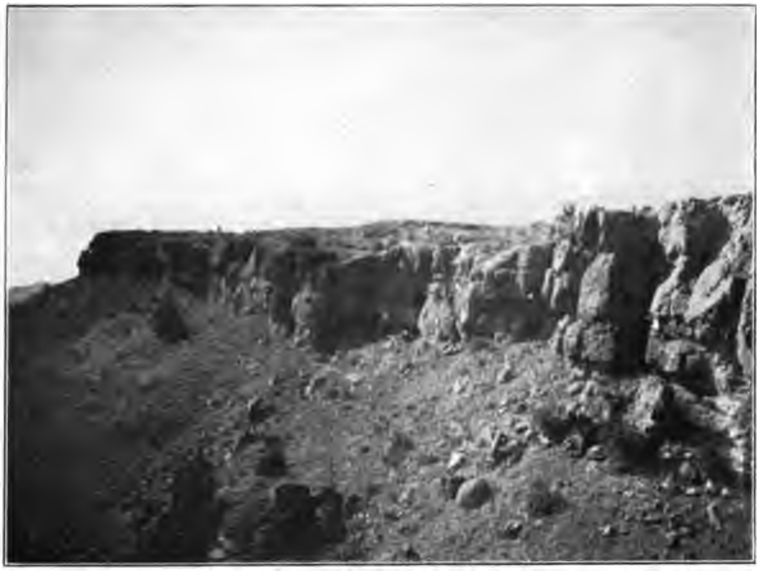
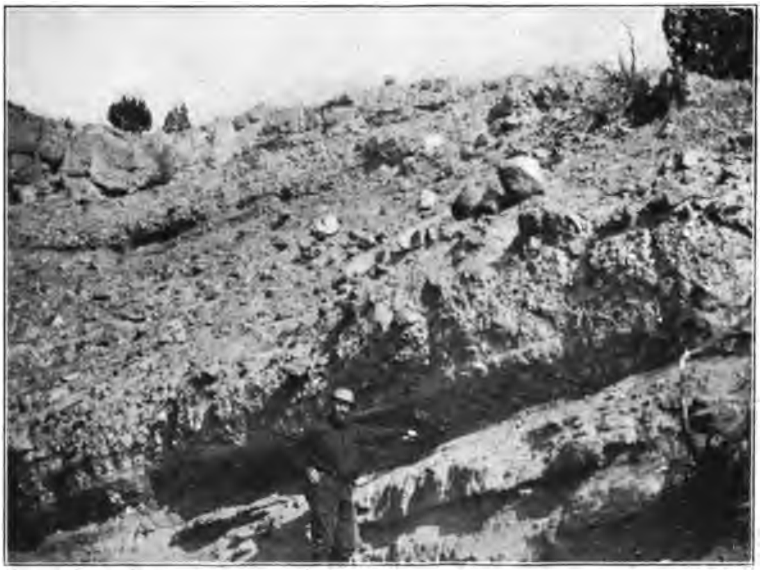


FIG. 12. San Marcos Arroyo. Gorge through narrow ridge of hornblende andesite.

The Cerrillos Hills present some obscure relations, but from the evidence just set forth the laccolithic origin of the hills is apparent. Regarding the exact number and relations of the several laccoliths I am in doubt. The following conditions seem to me most probable, although I am far from asserting them as certainly true.





TWO VIEWS OF BEDS OF VOLCANIC BRECCIA INTERSTRATIFIED WITH SANDSTONES OF THE GALISTEO GROUP, EAST OF THE CERRILLOS HILLS.
(Showing stratified character of breccia.)

The earliest intrusion was that of the hornblende andesite, which now forms the eastern foothills of the Cerrillos group. This andesite is cut by dykes of the later intrusive. In it are a number of inclusions of the upper Cretaceous sandstones (Madrid and Galisteo Groups), while near its western limit is found a small exposure of the volcanic breccia (Galisteo age), dipping off to the west. The western limit of this rock was difficult to determine, so closely does it resemble the later intrusion of augite andesite. The contact between the two, as shown on the map, is only approximately correct. This older laccolith sent off sheets into the surrounding beds, some of which are still well shown in San Marcos Arroyo. With it were several subordinate laccoliths, one of which is fairly well exposed east of Cerrillos. That it was asymmetrical is indicated by its abrupt southern face, near which the beds are vertical, while to the north it slopes more gradually, beds between it and San Marcos Arroyo dipping northward from it at a much lower angle. This subordinate laccolith is the only one in the group upon the top of which I found any sediments. On its northern slope were some thin sands and shales, not wholly eroded. At its base, also, I made out uncertain evidence of the underlying shales. It was intruded in the highest shale bed of the Madrid Group, as shown in Fig. 4, which represents the contact of these beds with the eastern side of the laccolith. Farther north, the beds in San Marcos Arroyo dip north, indicating the position of another of these smaller laccoliths. The Santa Fé Marls conceal the area just south.

Just what relation this intrusion bears to that of the augite-andesite series to the west, I am uncertain, but it seems most probable from the field relations that the later intrusive was injected west of the older laccolith, but spread eastward to join with it. It may, indeed, have enlarged that laccolith by insinuating itself between its top and the overlying beds, having since been more or less completely eroded. In this connection it is interesting to note that a little of the typical augite andesite was found in several places over the hornblende-andesite area, where it occurs in small exposures of a breccia largely of hornblendic fragments.

It seems probable, from the relation of the sediments near the head of Achavica Arroyo, that the main body of the hills is composed of two adjoining laccoliths, one embracing Santa Rosa, Santa Rosita, Lueras and Achavica Mountains, the other Mount

McKensie, Grand Central Mountain, and the whole of the southern foothills. From Lueras Hill a broad sheet or subordinate laccolith extends southwestward, capping beds which dip toward the east. The beds still farther west show a westerly dip, possibly indicating the position of another laccolith not yet exposed. The greater part of these laccolithic masses seem to be intruded in Fort Pierre shales. Near Cerrillos, however, Fort Benton shales occur, apparently as a small block faulted into an abnormal position. These shales dip in toward the hills, instead of away from them.

Of the outlying subordinate laccoliths Rocky Butte (Plate L), a mile or two to the northeast, is the only one near which the older sediments are exposed. Just east of it the red sandstones of the Galisteo Group are vertical and strike northeast and southwest. Columnar structure is well developed in this hill, the columns being vertical, and so proving that it is not merely the remnant of one of the radial dykes.

Gray Hill, Turquoise Hill (Plate O) and Bonanza Hill, to the northwest, are similar subordinate laccoliths, but are wholly surrounded by the horizontal beds of the Santa Fé Marls. Whether these have special conduits beneath them, such as dykes from the main hills, perhaps, or whether they represent local enlargements of sheets spreading out from those hills (bearing the same relation to them that the Mato Tepee does to the Little Missouri Buttes, according to Jaggar) can only be conjectured.

The symmetrical basalt cone, Mt. Calvary (Plate I), at the north, is surrounded by Santa Fé Marls except at its western base, where a little of the volcanic breccia found in the Galisteo Group is exposed. The facts that the rock is not vesicular, nor fragmental, but is hard and dense, and shows evidence of having cooled under pressure; that there is no evidence of any lava flow having ever been associated with it; and that the hill is so strikingly symmetrical, suggest that it is the remnant of an eroded laccolith. But this would necessitate the assumption that the ultra-basic limburgite composing this hill was intruded long before the related limburgites occurring in the more recent dykes, since such an intrusion must have occurred when there was a great mass of overlying sediments. While not impossible that we may have two rocks almost identical in all their characters, but of widely different age, it is nevertheless a questionable hypothesis. To regard this hill as the neck of an old volcano would necessitate the assumption that the Santa Fé Marls were thicker here and an overlying crater and flow have been completely eroded, which seems most unlikely in view of the relations of the Marls to the other basalt flows in the region. If it represents merely a surface overflow from a dyke or other conduit, the petrographic features are certainly not what we would expect in a rock occurring in this manner.

The beautiful system of radial dykes is well exposed by the erosion of the softer beds in which they occur. Such a system of dykes has not been recorded in connection with any of the great type laccoliths of the west. The Crazy Mountains, where such dykes are most beautifully developed, are regarded as great "stocks," with only subordinate laccoliths associated, and the dykes radiate outward from the stocks. Dykes are mentioned from all of the laccolithic mountains described, but they occur above the laccoliths, below them, or scattered throughout the region, without any orderly arrangement. In the Cerrillos region, however, these dykes radiate outward from a common center, which is located toward the northern end of the hills. The low basaltic volcano to the northwest also marks a nucleus from which radial basalt dykes extend outward to intersect the older andesitic series. Several basalt dykes south and southeast of the hills have a trend which suggests their independence of the crater to the northwest. They may have come up from the reservoir below, along independent lines of fracture.

I do not believe that the radial dykes of the Cerillos region are due to radial fractures produced by the intrusion of the lava. Whatever the nature of the conduit, it was probably not of sufficient magnitude to produce the results noted. This would be especially true of the liquid basalt flow, the extrusion of which was so quiet as not to greatly disturb the horizontal Santa Fé Marls. The fact that these dykes were not contemporaneous with the greater masses is also attested by the notable difference in the rocks constituting the two. Were they the result of one intrusion, the rock in both should be the same. As a matter of fact the dyke rocks are more basic, as is so often the case. This is especially true in the case of the basalt, the flow being an ordinary olivine basalt with much plagioclase, but all of the dykes being composed of ultra-basic, feldspar-free limburgite. It is also found that the dykes cut the greater masses in places.

Pirsson has already offered a very plausible explanation of the phenomena of radial dykes of this type.* It is pointed out that when the surrounding beds lose the heat imparted to them by the eruptive mass, they will contract, producing cracks, which, if the beds be fairly homogeneous and undisturbed, will assume a more or less radial position. These cracks may then be filled with the lava from below, forming dykes which are of more recent age than the main masses. As a result of the continued differentiation of the magma in depth, such dykes are usually more basic than the earlier intrusives. It seems to me that such an explanation most readily accounts for the conditions which are found in the Cerrillos region.

It remains to note the evidence furnished by the position of these dykes regarding the relative ages of the Sandia uplift and Cerrillos intrusion. If the andesite were intruded in horizontal strata, the subsequent cooling and contraction would naturally develop vertical fissures. If the Sandia uplift then tilted the beds, the dykes which formed in these fissures would be tilted also. As a matter of fact the dykes generally appear to be quite vertical. The fact that only a few of the dykes approximately parallel to the strike of the beds are well exposed, as well as the possible complicating conditions which might destroy the original hypothetical simplicity, makes the evidence of only suggestive value.

General Physiography.

In the discussion of the origin of the Santa Fé Marls I have already considered the development of the great alluvial fans of the region, and the resulting topography. As was there explained, these Marls remain capping isolated mesas, or tongue-like ridges from the main body of the plains, where the Galisteo Creek and its tributary arroyos have not yet removed them. The main facts noted are these:

The Marls rest on the upturned edges of the Cretaceous beds. The contact shows a remarkably even plane truncating the easterly dipping sandstones and shales. Variations in hardness of the beds appear not to affect this plane, which, wherever exposed was uniformly even. The phenomena are essentially those described by Gilbert as the results of "planation." * Exposures nearer the Ortiz Mountains indicate that this rock floor rises toward the ranges with a gentle slope.

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* "Complementary Rocks and Radial Dikes," L. V. Pirsson. *Am. Jour. Sci.*, Vol. L., 1895, pp. 116–121.

The evidence would seem to indicate that subsequent to the Sandia and Cerrillos uplifts, and prior to the deposition of the Santa Fé Marls, the long-continued erosion of the first half of the Tertiary period reduced the region practically to a local peneplain, above which the several mountain ranges still projected as monadnocks.

I have called attention to the notable series of flat-topped hills along the Galisteo Creek and its arroyos, and which indicate the uniform level of the old alluvial plain, now being dissected. Much less noticeable is a second series of level platform-like elevations, about 75 or 100 feet lower than the former, and nearer the creek. These are also covered by the horizontal Santa Fé Marls which rest on the more or less evenly planed-off Cretaceous beds. We have thus two definite levels or terraces, each capped by the horizontal Marls. These two levels have been noted throughout the valley of the Rio Grande and its tributaries in many places. Hayden referred to a "double series of terraces" in a number of places in his report, as for instance, "The Rio Grande wears its way through these marls (Santa Fé Marls) with a bottom about two miles wide. On the west side are distinct terraces with the summits planed off smoothly like mesas. The first one is eighty feet above the river; the second one two hundred feet." †

As will be seen from the conditions in the Cerillos region, these terraces do not represent the type produced by a stream cutting out an old drift-filled valley. The terraces are cut in solid rock, and we apparently have a true case of terraces formed as a result of reëlevation of the region, allowing the streams to cut to a lower level than the floors of the old valleys in which they formerly flowed. In the bed of the Galisteo itself I have found traces of the old valley bottom, only seven feet above the present water level. Here, too, were remnants of the Santa Fé Marls capping the planed-off Cretaceous beds.

The Santa Fé Marls are found as mere remnants well up in every arroyo in the region. In the narrow gorges cut in the hard

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* Geol. of Henry Mts., pp. 126–133.

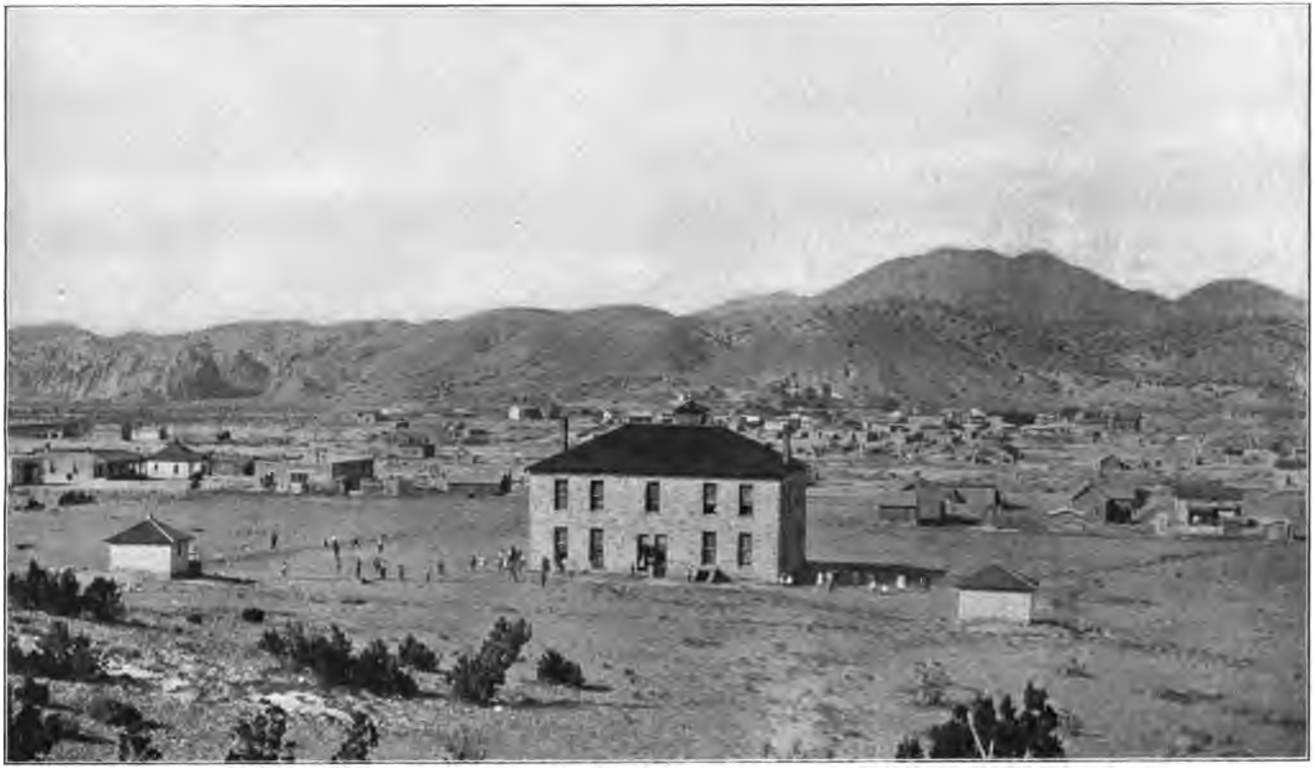
† Prelim. Field Rep. U. S. Geol. Surv., Col. and New Mex., 1869, p. 69.

rock of the Cerrillos Hills the marls are represented by narrow ledges of the peculiar conglomerate still adhering to the sides of the valley walls, or still persisting in places in the beds of the arroyos. This shows that the drainage of the region was fully established in its present relations, previous to the formation of these marl beds. The influence exerted by the Cerrillos laccoliths in the establishing of this drainage has already been suggested.

The history of the drainage relations, if my interpretation of the phenomena is correct, is as follows: After the great Sandia uplift, tilting the strata to the east, and the Cerrillos intrusion, doming the beds in the central portion of the area, the early Tertiary erosion removed a vast thickness of beds and reduced the area about the mountains to a gently sloping plain. During this time the Cerrillos laccolithic intrusion and the domed beds above it went through the cycles of radial and annular drainage, a portion of the annular drainage being inherited in the hard rocks of the outer edges of parts of the intrusives. When the area was practically reduced, the slightly lower level marking the junction of the gentle slopes from the Ortiz and Cerrillos regions doubtless marked the location of an east-and-west stream. As a result of elevation this stream again became active, cutting a valley 75 or 100 feet deep into the plain, and then spreading laterally until the valley was widened out to a considerable breadth. A second elevation caused the stream to cut still deeper. In the meantime the more detailed drainage about the foothills of the Cerrillos group, which latter remained porjecting several hundred feet above the level of the plain, was established.

Now the conditions changed. From one in which erosion exceeded the supply of material, there was a change to a condition in which the supply was greatly in excess of the ability of the stream to remove. Torrential mountain floods washed great sheets of coarse débris out over the plain, and down into the terraced valley of the stream, giving the coarse conglomerates of angular andesite fragments which we find lying directly upon the rock floor to-day. These alluvial fans gradually buried the old plain-like level, the valley and the tributary arroyos, so that the old river bed must have been more than 100 feet below the level of the alluvial plain thus formed.

In time a condition of equilibrium was reached, then passed, and the stream began to remove the marls. Sufficient time elapsed,



TOWN OF CERRILLOS AND SOUTHERN PART OF CERRILLOS HILLS. (Portion of great intrusive sheet shown at extreme left.)

however, for these marls to become quite compact in places before the valleys were again revealed, so that the lime-cemented conglomerate formed resistant beds which persist to-day, even in the beds of the streams as well as projecting ledges high up on the sides of arroyos from which all the rest of the Marls have been removed. This erosion is still being carried on, the old valleys being revealed, and cut still deeper. Near Waldo the present stream bed is several feet below the lowest level capped by the conglomerate, while toward the head of San Marcos Arroyo the Marls have not yet been cut through to the old stream bed.

General Geologic History.

As shown in the Sandia and other mountain ranges in this general region, the lowest beds represented are Upper Carboniferous limestones and sandstones which rest directly upon a floor of granite or ancient (Algonkian?) metamorphosed sediments. So far as the evidence shows, there is no stratigraphic unconformity from these Upper Carboniferous beds to the top of the Cretaceous, although such unconformity may exist and not be apparent.

Upon a floor of ancient crystallines, then, Upper Carboniferous limestones and sandstones were laid down. These were followed by the "Red Beds" of Permo-Triassic (?) age, consisting largely of massive and loose red sandstones, variegated marls and some beds of gypsum. Next came the sandstones and shales of Dakota (?) and Fort Benton Cretaceous age.

At this period volcanic activity developed, and flows of mica andesite were poured out over the Fort Benton shales. It is also possible that augite and hornblende andesites were represented in the eastern part of the area, in more massive development, as fragments of such rocks are found in later breccias.

The deposition of the Cretaceous sediments continued throughout the Fort Pierre epoch, shales being the prevailing deposit until toward the end of the Fort Pierre, when massive sandstone beds were laid down. At the beginning of the Fox Hills epoch the lignite beds of the Madrid Group were formed. Then followed the deposition of a thousand feet or more of yellow massive sands. These were followed by fifteen hundred feet or more of the red sandstones of the Galisteo Group. The land area was not far distant, and many tree trunks and branches were washed out over the sands and buried.

Along this shore line a violently explosive volcano now became active, and the showers of rock, sand and ash which fell in the shallow water near the land were sorted by waves or currents, and so formed fairly well stratified deposits. The volcano blew out fragments of the old crystallines far below, as well as large and small masses of andesite from some old flow or intrusive. The activity ceased from to time, and lenses of the red sandstone formed before the next outburst. Finally the volcano became extinct, and more or less of the red sandstones formed above the volcanic breccias.

Now came the great Sandia uplift, tilting all of the beds to the east, and producing great north-and-south fractures and faults. Along one such line of weakness andesitic lavas rose to the level of the Cretaceous beds, and then spread laterally to form several groups of laccoliths, the most northern of which was the Cerrillos intrusion.* There were at least two or three stages of this intrusion, the earlier hornblende andesite of the Cerrillos Hills, for instance, having time to congeal before the augitic rocks were intruded. Intrusive sheets were formed contemporaneously with the laccoliths, and some of these sheets having their origin in the Ortiz intrusion farther south, spread out into the lower beds of the Madrid Group, several of them between the various beds of lignite.

The heat from the intrusive lavas spread through the associated sediments, producing profound metamorphism in places, and necessarily effecting a rearrangement due to expansion. The lignites of the Madrid area were gradually transformed to bituminous coal wherever the intrusive sheets were only separated from them by a hundred feet or so of shales. Where the sheets were nearer the lignite was transformed completely to anthracite, while in cases where the lignite was a considerable distance from the intrusive it remained unaltered. Some of these sheets cut through the lignite in passing from one horizon to another, and near the direct contact the carbonaceous bed was burned to a natural coke.

In course of time the intrusive and the surrounding sediments began to lose their heat, and contraction took place. As a result

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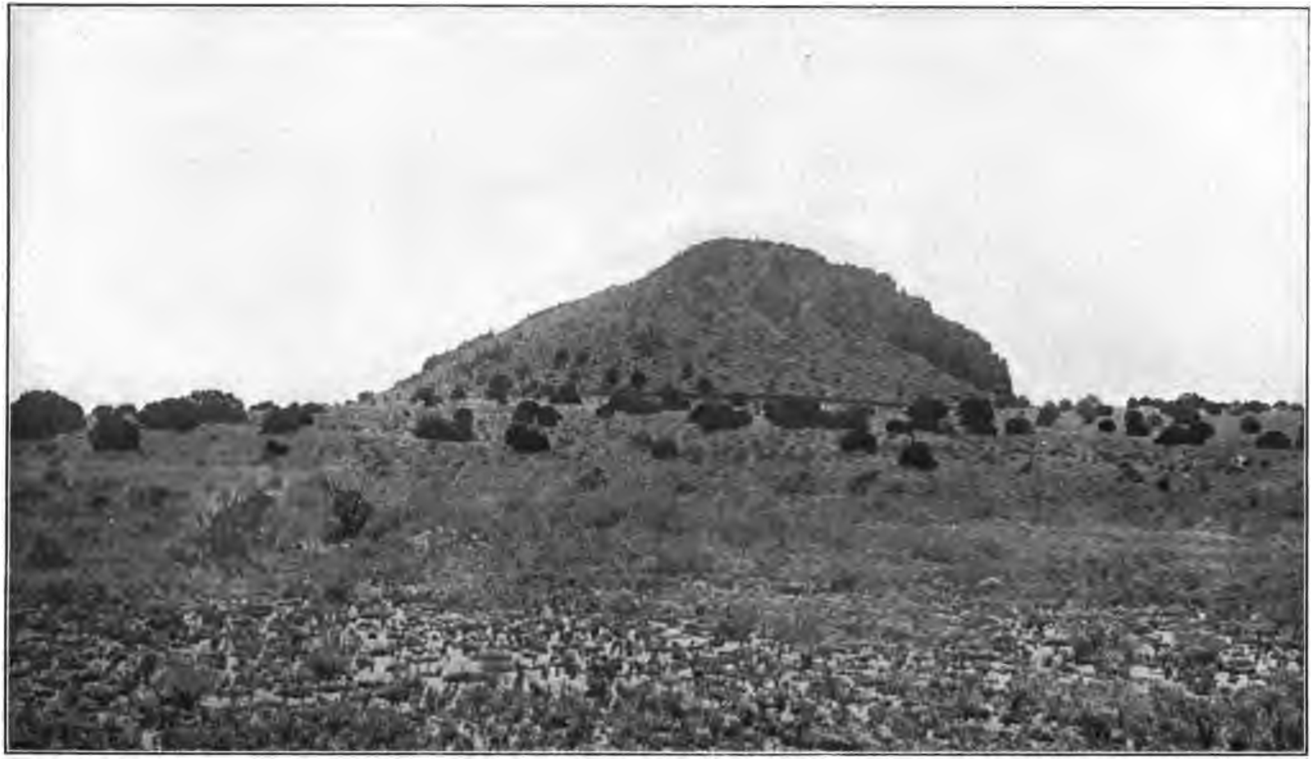
* My reasons for regarding the Sandia uplift as prior to the Cerrillos intrusion are based mainly on the theoretical considerations brought out in the text. There seems to be corroborative evidence in the asymmetrical laccoliths, which cut lower formations to the west than to the east, and in the vertical position of the radial dykes. I know of no absolute proof as to which was first.

Plate L.



ROCKY BUTTE. [Columnar structure (columns vertical) well shown on eastern half of hill.]

of this contraction more or less radial cracks were formed. Into these the molten magma was intruded from below, giving a beautiful series of radial dykes.

Meanwhile the erosive agencies far above were actively removing the overlying beds. Throughout the whole of the early Tertiary and probably up to the beginning of the Loup Fork period, this erosion continued. At last the laccoliths and their associated dykes were laid bare, maturely dissected, and the whole of the surrounding country reduced to a nearly level rock floor. Sheet-flood erosion was doubtless an important factor in this process of "planation." At this period a stream probably occupied a slight east-and-west depression between the Ortiz and Cerrillos Groups, being nearer to the smaller, or Cerrillos, Group. Remnants of the more or less annular drainage from the laccoliths doubtless persisted also.

Then came an elevation which permitted the east-and-west stream to cut a valley 75 or 100 feet deep in the old rock floor. Lateral corrosion widened this valley to a considerable extent when a second elevation allowed the stream to cut a second valley in the older valley floor. In this way two distinct terraces of solid rock were formed.

Great mountain torrents washed vast quantities of coarse, angular débris out over the surrounding country. The result was the formation of a conglomerate of angular fragments of the andesite, cemented by a calcareous cement, over nearly the entire area, relatively few places being left bare to be covered by the finer materials. As this conglomerate is found covering both series of terraces, and even the old beds of the streams, it is evident that the débris was able to fill up the old drainage valleys at once. Remnants of the conglomerate high up on the valley sides, and in the neighboring arroyos, show that the bottom of the lower valley of the main stream must have been buried under more than 100 feet of this débris.

The accumulation of this débris in the form of great alluvial fans continued, finer marls and sands soon predominating in the more distant portions of the fans, but frequently alternating with coarser, and even conglomeritic layers. By the lateral and distal confluence of these fans from the same and neighboring mountains, a great alluvial plain of the Santa Fé Marls was formed, sloping gradually from the mountains in all directions.

At this time occurred the extrusion of the basalt northwest of the hills. The liquid lava flowed out over the marls from the low crater (Plate H) which still remains, in part. It is possible that this eruption developed the stresses which caused faulting of the andesitic dykes, which is quite noticeable over the whole area. Or both the faulting and the eruption may have resulted in part, at least, from the continued activity of the Sandia uplift. The latter would seem most probably the cause of the extensive shearing throughout the Hills, along lines striking a little east of north (see Plate P). More or less mineralization of these sheared zones occurred, and some true fissure veins were formed. Some of the sheared areas were profoundly altered, and turquoise formed among other secondary products. The heat from the eruption effected more or less expansion and rearrangement in the underlying beds. As this heat was lost, contraction produced radial cracks, which were then filled with an ultra-basic type of the basalt, giving basic radial dykes.

In the meantime the deposition of the Santa Fé Marls continued, and a part of the eastern edge of the basalt flow was buried under a thin cover of these deposits. Finally a condition of equilibrium was reached and then passed, when erosion began to exceed deposition of these fans. The main stream (Galisteo Creek) and its tributary arroyos soon revealed the old valleys, removing the looser marls, but leaving the resistant conglomerate, capping the series of terraces, and in places covering the stream beds. This activity worked headward along the streams, so that the marls are less completely removed toward the head of the Galisteo and the larger arroyos, while farther west the creek has cut several feet below the bottom of the old buried valley, and removed great quantities of the marls and soft Cretaceous shales. This erosion is still in progress, working toward a reëstablishment of the conditions which existed prior to the deposition of the Santa Fé Marls.

ECONOMIC GEOLOGY.

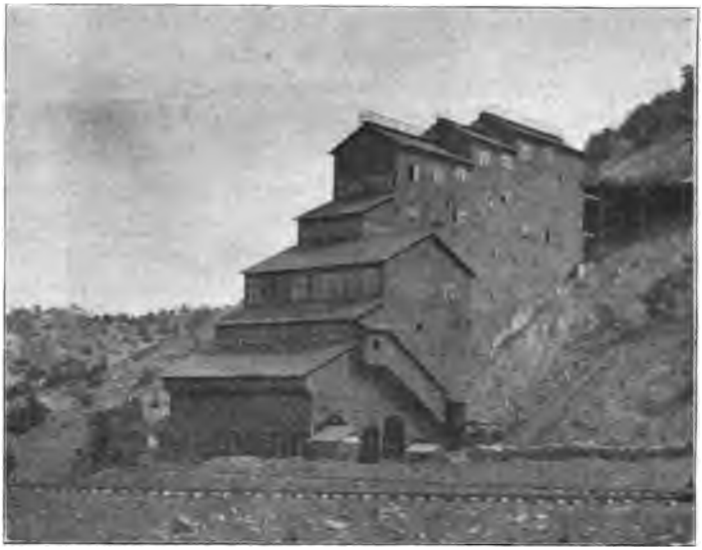
Coal.

From the economic standpoint, the most important product of the Cerrillos region is the coal of the Madrid field. The mines were operated in a small way for a number of years before the industry was put upon a firm basis in 1891. Since that time the anthracite and bituminous coal of this region have played an important part in southwestern markets, first under the control of the Atchison, Topeka and Santa Fé Railroad Company, and since 1899 under that of the Colorado Fuel and Iron Company.

At present three of the mines are being worked, on as many different seams. They are known as the Cerrillos Bituminous No. 27 (formerly Cook and White), the Cerrillos Anthracite A No. 28 (formerly Lucas), and the Cerrillos Anthracite B No. 33 (recently opened). The first of these mines is located at the town of Madrid, on a seam three and a half feet in thickness, and is opened by triple slopes driven downward along the easterly dip of 15 degrees, to a depth of 2,930 feet. An excellent quality of bituminous coal is produced. The Cerrillos Anthracite A No. 28 is located near the former, but on a seam some 200 feet higher. This seam is three feet thick, dips 15° east, and is opened by a slope 2,600 feet in depth. The best of true anthracite coal is produced. Just above this seam, and separated from it by only a few feet of sandstone, is one of the sills of andesite 130–160 feet thick. Above this easterly dipping sill, and separated from it by a thin stratum of sandstone, but half a mile east of Madrid and consequently at a lower altitude than the former mine, is a four-foot seam of good anthracite in which the Anthracite B No. 33 mine has been recently opened.

The total output of these mines, as given by the mine inspector, for the fiscal year ending June 30, 1901, was: bituminous coal, 75,295 tons; anthracite, 41,264 tons. The anthracite coal from both mines is screened and sorted in a large breaker near the northern end of the village. At Waldo are fifty bee-hive coke ovens where a portion of the product of the mines is reduced to coke.

The anthracite coal of this region has proven of special interest to the geologist, since in places it occurs in the same bed with bituminous coal, and was evidently produced by the metamorphic action of the intrusive. Associated with the coal are the intrusive sheets, or sills, already referred to, several of the radial dykes from the Ortiz and Cerrillos intrusive centers, while two or three miles farther south is the main mass of the Ortiz Mountains. Several theories have been advanced as to which of these three forms of eruptive was the active agent in effecting the transformation to anthracite. By a few the radial dykes which cut the coal, especially the big Madrid dyke which must have passed just along the present face of the main escarpment into which the mines were opened, have been regarded the true causes of the change. By most geologists the great sills which were intruded in the beds above and below the coal have been regarded as the efficient agents. This is the view which my own observation led me to adopt, and which is supported below. At first thought it might appear of value to give in detail the published opinions of those geologists who support this theory. So far as I am able to learn, however, their conclusions were based on no close study of the conditions, and so must be regarded rather in the light of suggestions. It may be said that the mine workers themselves believe in these sills as the sole agents in the transformation, and claim they can always foretell the close approach of the sheet by the variations in the coal.



From *Camp and Plant.*

FIG. 13. Anthracite Breaker, Madrid.

Far more weight, however, must be given to the conclusions of Professor John J. Stevenson, who considers the main mass of the Ortiz intrusion farther south as the only effective agent in producing the transformation. So far as I am aware Professor Stevenson is the only one who has given any detailed study to this special problem, and his excellent work, although necessarily limited to but a few days, can only command the most thoughtful consideration. In presenting my own views I shall accept Professor Stevenson's observations of phenomena as unquestionably correct, but endeavor to show how they will bear another interpretation, more in accord with certain theoretical considerations and some additional facts brought forward.

The main facts set forth in Professor Stevenson's discussion are as follows:

(*a*) In the upper one of the two main workable seams, known as the Lucas bed (same as White Ash bed), the coal toward the south, nearer the intrusive mass of the Ortiz Mountains, is all anthracite; at the extreme north of the workable area, farthest away from the intrusive mass, the coal in this same bed is largely bituminous; between the anthracite and bituminous is a broad area (3,000 feet along Coal Gulch) largely of soft, friable, "tender" coal which is unmarketable, but with some good anthracite in places.

(*b*) In the lower of these two main seams, known as the Cook and white bed, the coal farthest south, as indicated by fragments on dumps of old openings, is anthracite; the coal as found in the opening at the southern end of the village, directly under the "tender" coal of the seam above (which contains some anthracite even farther north) is a somewhat tender bituminous coal; the coal farther north was not well exposed, and no analyses were available.

(*c*) In the thin seams between the above two main beds, the coal farthest south, even two miles or more above the Lucas (anthracite) mine, is bituminous and shows no evidence of change.

(*d*) A drill hole west of Coal Gulch shows bituminous coal eight or ten feet above a sill 200 feet thick. The coal was not appreciably changed.

(*e*) The interval between the Lucas (White Ash) bed and the sill above it shows no great variations along the mesa front in Coal Gulch; "yet in the Lucas mine and all points examined south from it the coal is anthracite, whereas at all points north from it to the border of the eruptive rock one finds only transition coal."

(*f*) The coal was crushed into fragments, slickensided, and laminated.

Upon the above facts Professor Stevenson based the following conclusions:

"Mere proximity to a mass of eruptive rock is insufficient to produce any material change in the coal."

"Direct contact appears essential to change."

"The coal was changed into anthracite solely by contact of the beds with the enormous mass of eruptives" (two or three miles to the south).

"The coal was completely formed when the disturbance took place."

The facts above noted, upon which these conclusions are based, I accept without question. It does not appear to me, however, that the conclusions given necessarily follow. For instance, granting for the moment that the intrusive sheets, or sills, were the active agents, then:

(*a* and *b*, see above) If the intrusive sheets above and below the coal seams were very thick nearest the main mountain mass, but thin out and disappear to the north, or if they were nearer the coal at the south than at the north then we could conceive that the beds might be of anthracite toward the south, nearer the mountains, but bituminous farther north where the sheets were thinner and had less heat to yield for the metamorphic action, or where the sheets were farther away from the coal.

(*c*) The thin seams between the two main beds would then most naturally be of bituminous coal even far to the south, if not near such an intrusive sheet.

(*d*) It is conceivable that local cases of abnormally slight metamorphism might occur, in which lignite quite near an intrusive sheet would only be changed to bituminous instead of anthracite coal. Cases of such unequally distributed metamorphic action are so abundant in the literature of metamorphism as to need no detailed comment.

(*e*) As noted above (*a* and *b*), the occurrence of anthracite to the south and transition coal to the north, might be possible if the sheet thins out toward the north, regardless of minor variations in the distance of this sheet from the coal; while the fact that "at all points north from it (Lucas mine) to the border of the eruptive rock one finds only transition coal," whereas beyond the border of the eruptive we pass into bituminous coal, is exactly what we should expect on the basis of our assumption.

(*f*) If lignite were transformed by such sheets into bituminous coal and anthracite and then a later movement due to contraction, the intrusion of dykes or some other disturbance were to take place, we could get the crushing into fragments, slickensiding and lamination, even though the coal was not completely formed when the first intrusion took place.

It is evident, then, that there is a possibility of placing an entirely different interpretation upon the facts noted by Professor Stevenson, provided that certain geological conditions are found in the area in question. As will appear, such conditions are found in the Cerrillos region; and they, in the light of several theoretical considerations and a number of facts to be noted, afford strong evidence in favor of the following conclusions:

The coal was probably in the form of lignite before the intrusion occurred.

This lignite was changed to bituminous and anthracite coal by the metamorphic action of the intrusive sheets or sills.

Mere proximity to these sills was sufficient to produce these changes.

Direct contact destroyed both the bituminous and anthracite coal without the production of anthracite from the former.

First, with regard to the geological conditions as found in the area:

The intruded sheets or sills are thicker toward the south, nearer the main eruptive mass. With an understanding of the laccolithic nature of the main intrusion, we would naturally expect these sills to grow progressively thinner as they pass farther and farther away from the parent mass. This is not always the case, local thickenings sometimes occurring; but as a rule it is true. The case in point, however, is no exception to the rule. Professor Stevenson has already referred to this thinning out of each of the two main sills toward the extreme north. (C. C. F., pp. 109, 115, 121.)* This northward thinning is equally marked farther south. A recent drill hole southeast of the town struck this second sill at the proper depth; after cutting into the sill for several hundred feet the hole was abandoned. Farther northwest, the thickness, as exposed a little north of the line of the Madrid section (Fig. 5), was seen to be over 250 feet. Northeast of here, on the mesa, Professor Stevenson noted (C. C. F., p. 108) that the thickness, as shown by a drill hole, was only 200 feet. Its continued thinning out and disappearance to the north he referred to elsewhere, as noted above. This variation in the thickness of the upper sill is

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*This and the following similar references, refer to the pages of Professor Stevenson's paper on the "Cerrillos Coal Field," *Trans. N. Y. Acad. Sci.*, 1896.

Tough clay (moist),	.00310
Coal,	.00057–.00113

Professors Ayrton and Perry found the conductivity of

Porphyritic trachyte,	.0059

It readily appears that the coal having the highest grade of conductivity is only about one fifth as good a conductor as ordinary dry sandstone, or as an igneous rock similar to that in the Cerrillos district. This being the case, and assuming that this series of beds is cut by the great intrusive mass to the south, it is interesting to determine how much of the heat concerned in the transformation of the coal at a given point would reach that point through the coal itself, and how much would reach it through better conductors such as the intrusive sheet.*

According to a well-known thermal law, the amount of heat that will reach a given point is equal to the difference in temperature between that point and the source of the heat, multiplied by the cross-section of the body through which it passes, multiplied by the conductivity of that body, divided by the distance it has to travel. This may be expressed in the following formula:

$$h = \frac{(T - t)sc}{d},$$

in which $h =$ the amount of heat that reaches the given point, $T =$ the temperature of the source of heat, $t =$ the temperature of the given point, $s =$ the cross-section of the body through which the heat travels, $c =$ the conductivity of that body, and $d =$ the distance the heat travels in reaching the given point.

Applying this law to the case under discussion, we have the intrusive mass of the Ortiz Mountains as the source of heat, while any portion of the anthracite bed will be the given point. We are to consider whether more heat will reach this given point through the coal itself or through the overlying intrusive sheet and the intervening sandstone and shales. For the moment we will neglect the additional heat of the sill itself, and see what the result would be if it were only the same temperature as the coal. As shown by Professor Stevenson, and noted by myself, good anthracite is found at least two or three miles away from the intrusive mass of the Ortiz. Let us then assume the smaller number, two miles, as the distance, along the coal bed from the source of heat. The distance along the intrusive sheet and then down to the coal, would be this two miles plus the twenty-five to fifty feet of intervening sandstone and shales. In a distance of over 10,500 feet, twenty-five or fifty feet is a negligible quantity and may be dropped out, especially since the conductivity of the sandstone does not differ greatly from that of the sill, and since in some places the sill is only ten feet from the anthracite. In so short a distance the difference in conductivity across and along bedding would also be so small, relatively, as to be negligible. As the given point and the source of heat are the same in both cases, the difference in temperature $(T - t)$ will be the same in both cases, and may be stated as n degrees. The sill varies from at least 100 to 150 feet in thickness in the region in question, while the coal averages about three feet, the highest record being given as seven feet. If we take the lowest estimate for the sill, and the very highest estimate for the coal, then over any given area the sill will have a cross-section over fourteen times as great as that of the coal; whence $s = 1$ in the case of the coal, and $s = 14$ in the case of the sill. Taking the highest figures given for the conductivity of coal, we have $c = .00113$ in the case of the coal, and $c = .0059$ in the case of the sill. Substituting these values in the above formula, we have

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* I submitted this problem to Professor Wm. Hallock, of Columbia University, and for his criticism and suggestions concerning the points noted below my acknowledgments are due.

$$h = \frac{n \times 1 \times .00113}{2} = .000565n$$

as the amount of heat reaching the given point through the coal itself, and

$$h = \frac{n \times 14 \times .0059}{2} = .0413n$$

as the amount of heat reaching the given point through the intrusive sheet. In other words over 73 times as much heat would reach the given point in the coal seam by coming through the intrusive sheet as would reach the same point through the coal itself.

This estimate is based on the worst possible conditions for the transmission of heat through the sill, and the best possible conditions of transmission through the coal. A similar calculation, assuming average thicknesses of beds, conductivities, etc., gives a result of over 300 times as much heat coming to a given point through the sill as through the coal itself. The latter estimate is probably much nearer the truth than the former.

The above must be considered as only a rude approximation, so far as actual figures are concerned. But while the real conditions are far less simple than assumed above, owing to conductivity of heat by way of intervening sandstones, etc., the essential truth is clearly shown. Even had the sills no heat of their own, they would convey to the coal, as intermediate agents, vastly more heat that it would be possible for the coal itself to transmit. It may be doubted if the sills would conduct enough heat for two or three miles to effect the transformation to anthracite. Then, in the terms of our most conservative figures, it is seventy-three times as doubtful that the coal itself could transmit sufficient heat to accomplish the change.

The presence of water (conductivity = .00136) in the coal might increase its conductivity to some extent, but even if we were to suppose an improbable amount of moisture the increase would not be enough materially to affect the above figures. And at the same time the presence of water in the neighboring beds would correspondingly increase their conductivity.

So far we have ignored the actual heat of the sills themselves. If, now, we consider the initial heat of the intrusive sheets, sometimes over 300 feet in thickness in the Madrid area, we have a most reasonable explanation of the source of the transforming energy. The heat would readily spread through the thin beds of sandstone and clay shale, which are fairly good conductors, to the coal only a few feet distant. The rise in temperature, the resulting increased chemical activity and the possible influence of hot water and vapors, are all factors to be considered in connection with the change.

There are a number of facts which confirm the theoretical conclusions deduced. As shown in the Madrid section (Fig. 5), the upper large seam of coal is only a few feet from the sill above it. This coal is good anthracite. The lower seam is several times as far away from the sill nearest it, the one immediately below. This coal is bituminous. Midway between the two sills and so quite a distance from the intrusive, is a bed of shale with considerable unchanged brown lignite. It is difficult to account for this condition upon any other hypothesis than the one now supported, that the sills were the active transforming agents. Believing this to be the case, we can readily understand how the heated lava, intruded as sills between a series of lignite beds, would produce the greatest change on the nearest beds making anthracite, affect those beds farther removed less profoundly giving bituminous coal, while the beds still more remote would remain as unchanged lignite.

It is interesting to compare the analyses of the coal and lignite from the above three seams. In the table given below the analyses, for which I am indebted to Mr. C. H. Decker of the Columbia School of Mines, have been recalculated on an ash-free basis, in order to afford a better means of comparison with the lignite in the lignitic shales. For while the brown lignite is well shown, and preserves the woody structure with great fidelity, it only constitutes about 22 per cent. of the samples secured. This does not affect the significance of the occurrence, since the presence of the foreign material would increase the conductivity of the beds, and facilitate the alteration of the lignite contained in them. In fact, similar beds near the upper intrusive sheet have been so altered, producing a peculiar, soft, black sandy rock. The anthracite and bituminous coal contained 7.70 per cent. and 5.04 per cent. of ash respectively. No. 1 is the recalculated analysis of the lignite in the lignitic shales from an exposure near the Madrid breaker, 134 feet or more from nearest intrusive sheet; No. 2 that of the bituminous coal, an average sample taken from carload just removed from bituminous mine near same point, 100 feet from nearest intrusive sheet: and No. 3 that of the anthracite, an average sample taken from carload from anthracite mine just above, less than 30 feet from intrusive sheet.

	No. 1.	No. 2.	No. 3.
Water	18.33	1.26	.86
Volatile hydrocarbons	61.91	36.49	6.55
Fixed carbon	19.76	62.25	92.59

The decreasing percentages of water and volatile hydrocarbons, and the increasing percentages of fixed carbon, from the beds farthest away from the intrusive to that nearest it, are even more striking than the variations in a north-and-south direction along the same bed, pointed out by Professor Stevenson. And while the latter variations are what we would expect on the basis of either theory, the facts just noted above offer serious obstacles to the theory of a change effected by heat traveling along the coal seams from the south, and strongly confirm the theory that the heat from the intrusive sheets alone was the transforming agent.

Professor Stevenson noted the fact that thin beds of coal between the two main beds above referred to remained good bituminous coal far southward into the region where the beds above and below were both anthracite (C. C. F., p. 120). He recognized that this fact appeared to contradict his hypothesis, but explained the phenomenon on the ground that these smaller beds were badly cut by clay seams, which would prevent the passage of heat from one portion to another. Clay which has been sun-dried, the poorest conductor among clays, is twice as good a conductor of heat as coal; while the same material in a moist condition is three times as good a conductor. The clay seams should facilitate the passage of the heat, especially since the great pressure of overlying beds would make perfect contacts between clay and coal, and it seems to me that this striking contradiction to Professor Stevenson's hypothesis remains unexplained. If we regard the sills as the active agents, however, it is readily intelligible.

It is also to be noted that in every part of the field the anthracite coal is invariably close to one of the sills. It is also true that the bituminous coal is generally farther removed, or occurs near where a sill is thinning out to disappear entirely. In this latter association we find the bituminous coal of the northern part of the Lucas (White Ash) anthracite bed. Professor Stevenson has noted that in a drill hole on the mesa west of Coal Gulch, bituminous coal was found only 8 or 10 feet above a sill 200 feet thick. It does not seem to me that this can in any way cast doubt upon the theory supported. For while we might say certainly that where metamorphic action has been effective it was due to a certain cause, we can never say that such action shall extend a given distance from its source. Evidences of the unequal distribution of metamorphic action about an igneous mass are too numerous to need comment. And while in a general way we should look for a certain degree of uniformity, isolated cases of less extensive activity should not occasion undue surprise. Moreover, the case in question is from near the northern limit of the sill, and the abrupt termination of the latter near that place, or a possible local thickening of the sheet bringing it so near the coal for only a very limited area, or the possible occurrence of a bed of loose sands (the thermal conductivity of which may sink as low as that of coal) between the coal and the sill, may explain the lack of excessive metamorphism on a most natural basis. That the bed was changed to bituminous coal, instead of remaining lignite, is evidence that the metamorphism was active to a considerable degree.

The fact that unaltered brown lignite, showing the detailed structure of the wood with remarkable clearness, occurs in the Cerrillos region where protected from the heat of intrusive sills by a considerable thickness of sands and shales and more especially by beds of poorly conducting coal, suggests that prior to the intrusion all the beds may have been of lignite. This conclusion gains weight from the fact that the lignites of the same horizon farther west are practically unchanged. After the transformation of the lignite into coal, as a result of the cooling and contraction of the beds, strains were developed, fractures and faults resulted, and extensive dykes were intruded. This accounts for the crushing, slickensiding and laminating of the coal, which is so prominent a feature in parts of the mines.

In his excellent paper on the "Coal Fields of Colorado," * R. C. Hills has noted the fact that every stage of alteration from true lignite to true anthracite is found in the Colorado fields in connection with the associated intrusives. One excellent example is reported from the Clear Creek basin, where an intrusive sheet of lava, twenty feet thick, is separated from a ten-foot coal seam by fifteen to twenty feet of shale. In one place the lava jumps down to within eight feet of the coal seam, and continues thus for about 300 feet. This near approach of the intrusive transformed the coal into anthracite. Hills regarded the intrusive sheets as active agents, and emphasized the importance of increased chemical activity due to elevation in temperature, aided by the action of steam and hot water. Direct contact with the intrusive was shown not to be essential, and the existence of the coal in the form of lignite prior to the transformation pointed out.

As has already been shown both theoretical considerations and the actual facts in the field show that the close proximity of one of the great intrusive sheets is sufficient to produce the transforma-

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* Coal Fields of Colorado, R. C. Hills, Min. Res. U. S., 1892, pp. 319–365.

tion from lignite into coal. Indeed, it would seem incredible that an imprisoned sheet of molten rock, of wide extent, and from 300 to 400 feet thick in places, should not have a profound effect upon carbonaceous beds only a few feet distant. In the same way, on *a priori* grounds, we might expect that actual contact with the intrusive would have a detrimental effect on the coal, since intense and sudden activity of this nature would tend more to char and destroy the coal than the slower and more steady action through protecting sediments. Observations in the Cerrillos field show that where a sheet or dyke cuts across the bed, whether it be bituminous or anthracite, the coal near the contact is destroyed, and in no case is anthracite produced from bituminous coal.

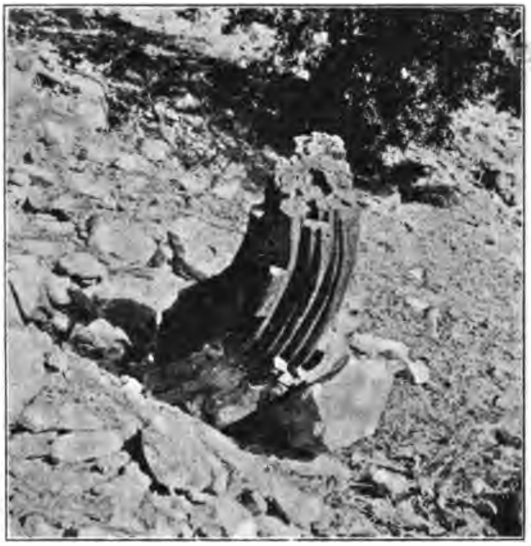

Fig. 14. Columnar structure in coal.

In the White Ash (bituminous) mine, now abandoned, a north-and-south dyke was encountered 3,600 feet from the mouth of the slope. For about 100 yards before the dyke was struck the bituminous coal was badly altered, being wholly worthless. So far as could be learned no anthracite was produced. This same obstruction was encountered in the Lucas (anthracite) mine 3,000 feet from the mouth of the slope, and the coal was similarly altered in the vicinity of the dyke there.

Professor Stevenson has already noted the influence of the Madrid dyke in effecting the change in the coal in a pit near the northern end of Madrid (C.C.F., p. 116).

In the Anthracite B No. 33 mine, east of Madrid, a sheet from below cuts up through the coal to a point just above it, and then follows along the bedding plane. The coal is excellent anthracite until within a hundred feet or so of where the sheet has cut it, when the change to soft, charred coal is noted. This "burned" coal from the anthracite bed is similar to the material produced in bituminous beds elsewhere by the same kind of action. In this same mine, in one of the right entries, the same sheet is encountered where it cuts up through the coal. At this point the coal is destroyed as before, while near the sheet beautiful curved, basaltiform columns of natural coke are formed (Fig. 14). The analysis of this coke, made by Mr. C. H. Decker, is given below:

Water,	4.55
Volatile hydrocarbons,	4.43
Fixed carbon,	84.67
Ash,	6.35
	100.00

In a coal mine east of the Ortiz Mountains a seam of bituminous coal is cut by one of the great radial dykes from that group. At the contact the coal is destroyed, while a short distance away, on either side, the bituminous coal is unchanged. Nothing in the nature of anthracite was produced.

The evidence points strongly to the conclusion that not only was direct contact not essential to the transformation of the lignite into coal, or of bituminous coal into anthracite, but that such direct contact tended to destroy both anthracite and bituminous coal alike, without producing anthracite from either lignite or bituminous coal.

SUMMARY.

The probable relations of the coal beds to the Ortiz laccolith, the laws governing thermal conductivity, the relations of the anthracite and bituminous beds to the intrusive sheets or sills, the extent and form of these sills, the occurrence of unchanged lignite where protected from the heat from these sills, the effects produced by direct contact of intrusives on both bituminous and anthracite coal at several localities and the evident sequence of geological disturbances in the area, together with other minor considerations, would seem to justify the following conclusions, which were outlined at the beginning of this discussion:

The anthracite and bituminous coal of the Cerrillos region were produced by the metamorphic action of intruded sheets of lava upon beds of lignite.

Direct contact was not essential to the change; on the contrary, direct contact destroyed both anthracite and bituminous coal without the production of anthracite.

More gradual thermal action through intervening protecting beds of sand and shale was conducive to the production of the best grade of coal.

The coal was crushed and sheared by movements subsequent to the intrusion of the sills and the transformation to bituminous coal and anthracite.

TURQUOISE.

The turquoise deposits of the Cerrillos Hills early attracted the notice of geologists and explorers in this region. In 1858, Professor W. P. Blake published a paper entitled "The Chalchihuitl of the Ancient Mexicans, Its Locality and Association, and Its Identity with Turquoise." * The paper discussed the extent and antiquity of the old workings in the Cerrillos Hills, the geological associations of the turquoise, and the characters of the gem.

In 1874, Dr. Oscar Loew visited the hills, and in his report † gives a brief description of the turquoise deposits, together with an analysis of the gem. This analysis, together with several others of the Cerrillos material, is given in Part III. of his report.

In 1880 Professor Benjamin Silliman studied the Cerrillos turquoise deposits, and published notes on the "Turquoise of New Mexico." ‡ Professor Silliman describes the ancient workings, discusses the character and origin of the turquoise, and the composition of the matrix. Illustrations of a longitudinal section and a distant view of the workings are given.

In the late '90's Dr. C. L. Herrick made several short trips to the Cerrillos district, and in a paper on "Geological Associations in New Mexico Mining Camps" § discussed the origin of the turquoise.

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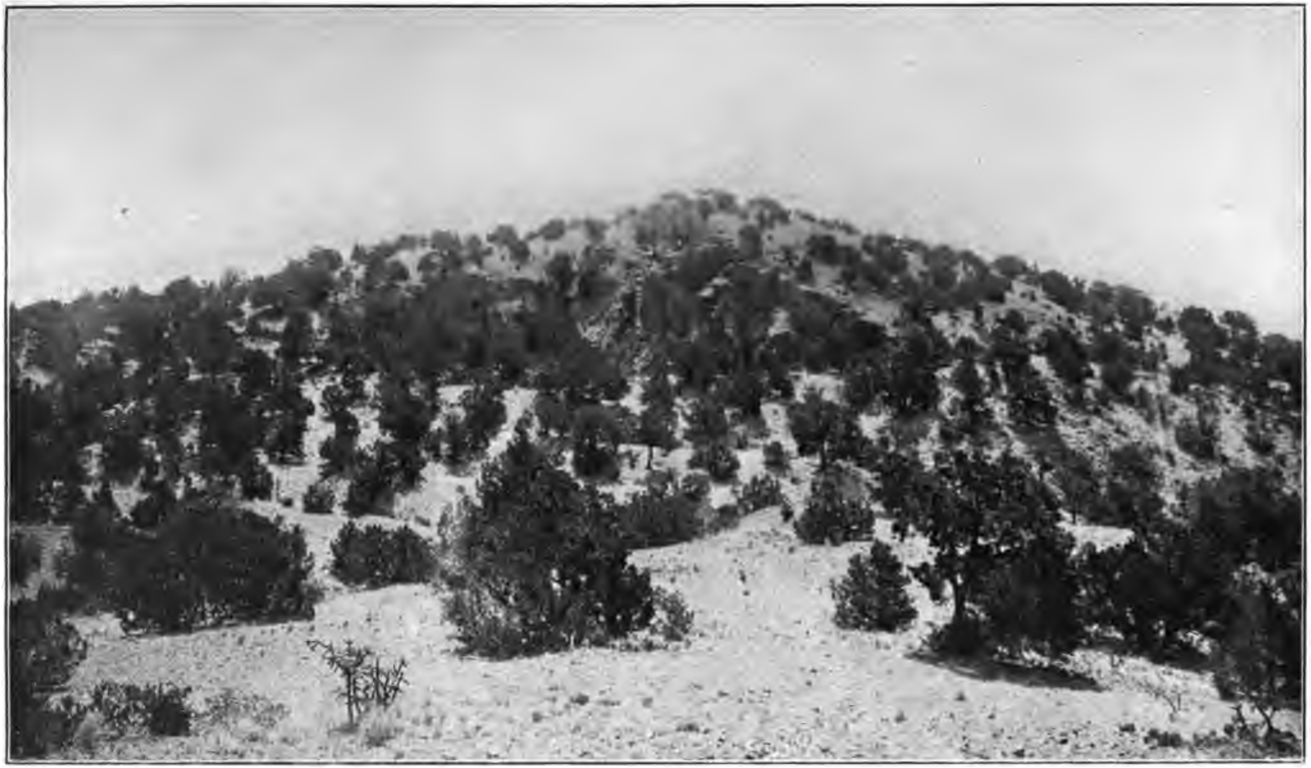
* *Am. Jour. Sci.*, Vol. XXV, pp. 227–232, March, 1858.

† Report of Chief of U. S. Engineers, 1875, Part II, p. 1027.

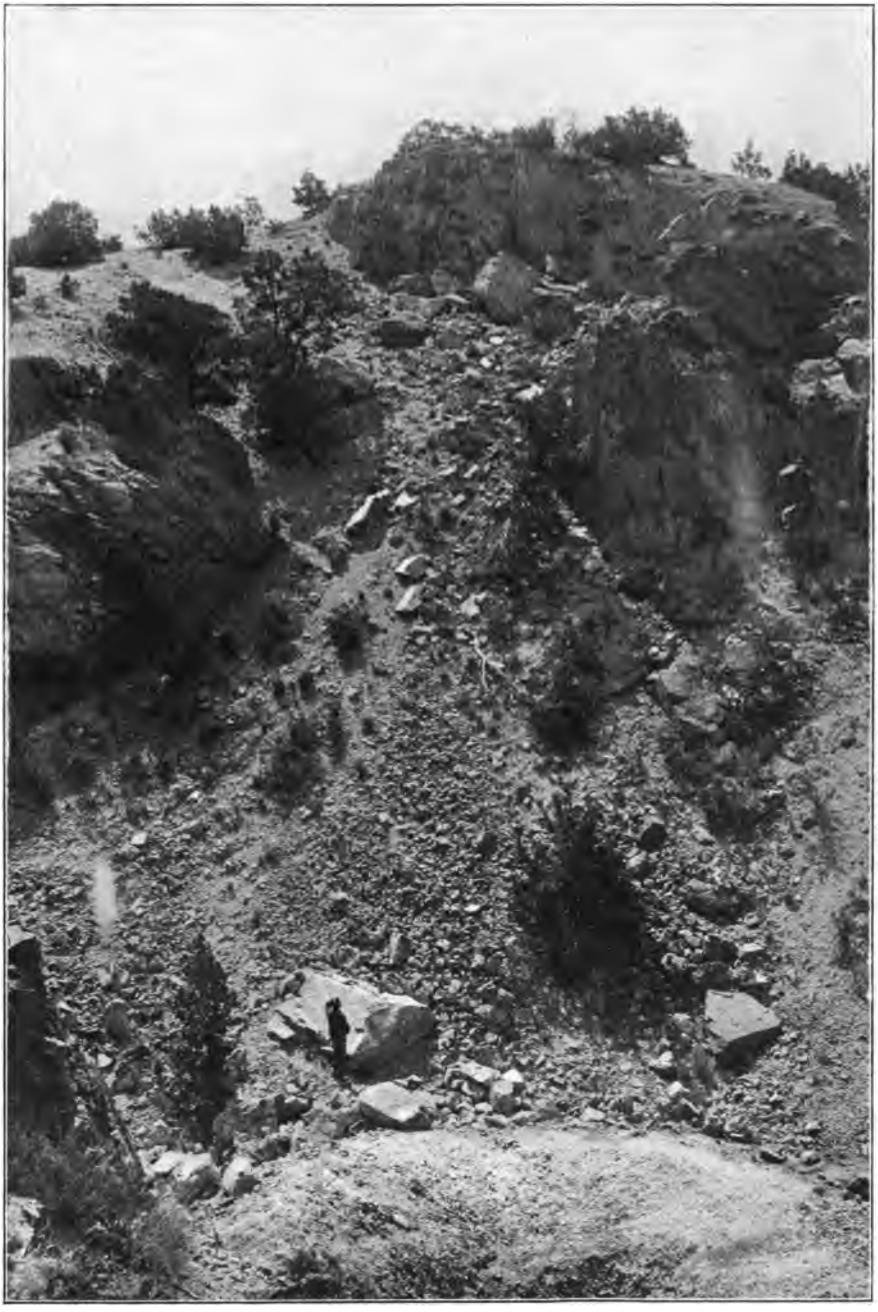
‡ *Am. Jour. Sci.*, Vol. XXII, 67–71, July, 1881.

§ Rep. of Gov. of N. M. for 1900, pp. 257–260.



MOUNT CHALCHIHUITL. (Showing portion of main excavation, with tree-covered dumps in middle ground.)

Plate N.



MAIN EXCAVATION IN MT. CHALCHIHUITL. (Showing extent of ancient workings.)

Professor J. S. Newberry (1859), Dr. J. L. LeConte (1867) and others made brief references to the turquoise deposits of this region, but gave no detailed descriptions.

In 1887 F. W. Clarke and J. S. Diller gave a detailed microscopical and chemical discussion of "Turquoise from New Mexico,"* based on collections made by Maj. J. W. Powell. The composition of the matrix was also considered and the origin of the gem discussed. A full review of their paper is given in connection with the discussion of the microscopical and chemical composition of the gem and its matrix, in Part III. of this report.

In 1900 Professor S. L. Penfield published an article on "The Chemical Composition of Turquoise."† An analysis of turquoise from Nevada is given, specimens of the Cerrillos material being examined and the analyses by Clarke, together with others, discussed. The copper is considered by Penfield as an essential constituent of the turquoise, rather than an impurity as suggested by Clarke.

The turquoise deposits of the Cerrillos Hills are found in two main localities, three miles apart. The extensive workings of the ancient Indians and Mexicans are located in Mt. Chalchihuitl (Plates M and N), a low knob east of Grand Central Mt. This is the locality described by Blake, Silliman, and others, and is of great historical interest. The hill is not represented by the contours on the map. Professor Silliman apparently confused Mt. Chalchihuitl, and the Grand Central Mt. just west. His descriptions of general appearance, altitude, etc., apply to the "dome" of Grand Central Mt., and do not apply to the low and inconspicuous knob of Mt. Chalchihuitl; whereas his descriptions of the rock, the excavations, and the cross-section and general view are of Mt. Chalchihuitl itself. In more recent years the mines have been worked to a small extent, but are now abandoned. The present workings of the American Turquoise Company of New York are situated at the southeastern end of Turquoise Hill (Plate O), a low ridge rising above the level of the plains northeast of the main group of hills. This locality is barely mentioned in the earlier descriptions, but was worked by the Indians probably as early as the more extensive excavations in Mt. Chalchihuitl, and in recent years has proven of more economic value. Other minor deposits have been opened up, but no extensive developments made. Some of these, also worked to some extent by the Indians and Mexicans, are found at the western end of Turquoise Hill.

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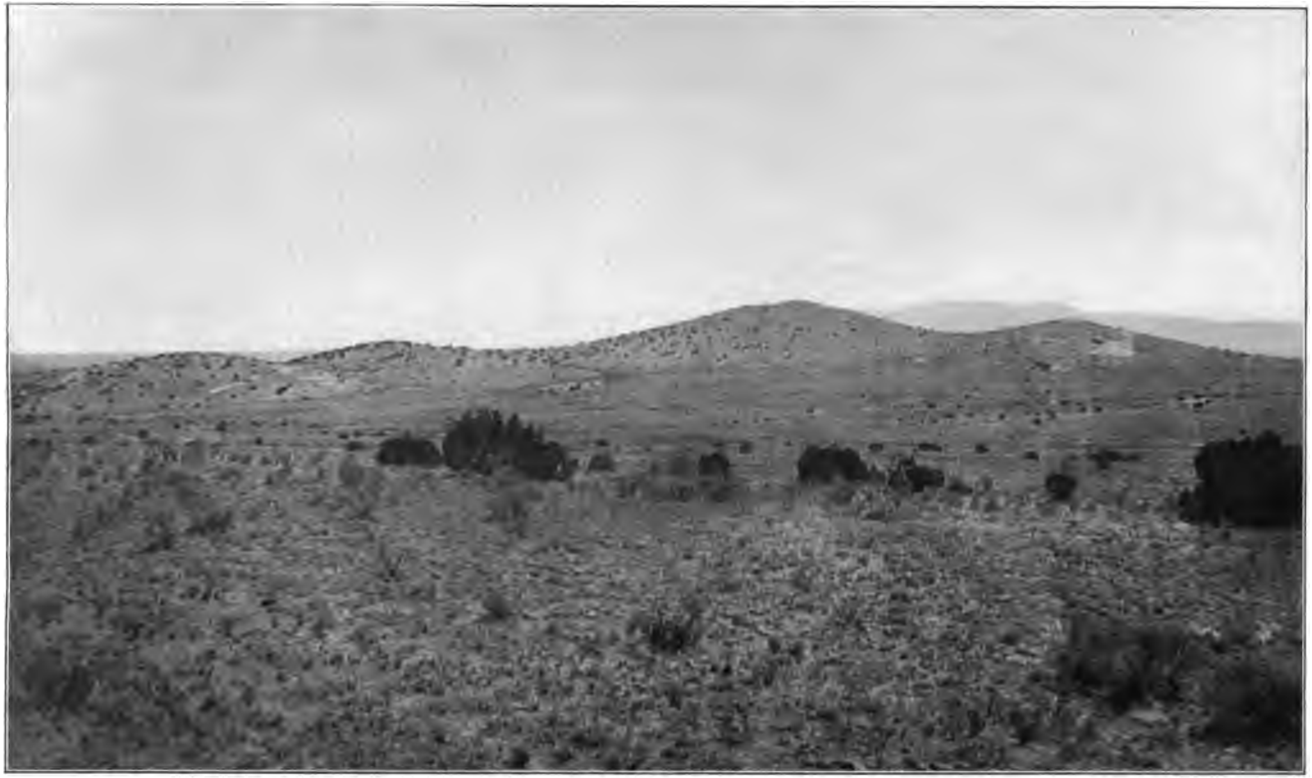
*Bull. U. S. G. S., No. 42, pp. 39–44.

†*Amer. Jour. Sci.*, Vol. X., November, 1900, pp. 346–350.

In all of these older workings the stone hammers of the ancient miners may be found to-day, although relic hunters have carried off the greater part of them, and only the more inferior specimens remain. The extent of the workings in Mt. Chalchihuitl is truly marvelous. The illustrations do not convey an adequate idea of the enormous mass of rock removed by the primitive methods of the ancients, although the figure in Plate N will give some conception of the depth which they reached. The whole north side of the hill has been quarried out in the search for the much prized "chalchihuitl," while less extensive excavations are found in other parts of the so-called mountain. It seems almost incredible that such a mass of rock could have been removed by a primitive people, without the aid of modern mining appliances. As Blake says, "This great excavation is made in the solid rock, and tens of thousands of tons of rock have been broken out." According to Silliman, a local surveyor found that the waste excavated in the old workings covers an area of at least twenty acres. All of the middle-ground in Plate M, on which piñon and cedar trees are growing, is débris from the workings just back, where the bare rocks are seen in the cliff. This "dump" forms a ridge or rim about the excavation, which latter extends to a depth not suggested by the picture.

The great antiquity of the workings cannot be doubted. The stone-hammers and fragments of pottery of the ancient miners, the rocks covered with lichens and gray with age, and the trees growing on the dumps and down in the pits, all bear witness to a period of mining activity centuries ago. Blake speaks of pine trees down in the pit which were over a hundred years old, while Silliman says their age must be reckoned by centuries. In 1680 a large mass of overhanging rock near the top of the cliff slid down, crushing a number of the Indian miners. This accident has been considered the immediate cause of the uprising of the Puebloes and the expulsion of the Spaniards in that same year. I was able to get far enough back through the débris of the slip to make out a part of the old roof of the cave formed by the overhanging cliffs. It was still black from the smoke of ancient fires, and served to give a very good idea of the great extent of the disaster.



Turquoise Hill. (Large dump from turquoise mine shown at the right.)

The rock forming Mt. Chalchihuitl and the western and eastern ends of Turquoise Hill, and in which the turquoise occurs, is fully discussed in Part III. of this report. As is shown there, this rock is an altered phase of the augite andesite forming the main portion of the Cerrillos Hills. The main large areas over which this altered rock prevails are shown on the geological map. Those areas at Mt. Chalchihuitl and at either end of Turquoise Hill are the only ones which so far as known, contain any notable amount of turquoise. The rock is yellow or white in color, sometimes mottled or streaked with iron stains. In cases it may resemble sandstone, but remnants of the feldspar phenocrysts are generally seen in the hand specimen.

The turquoise occurs as seams throughout the rock, filling crevices formed by crushing and shearing, and as little nodules in streaks or patches of kaolin. The color varies from green through greenish-blue to pure sky blue. Many of the specimens are marred by streaks of limonite, kaolin, etc., but some gems of rare beauty and purity have been secured, equal to the best Persian material. The microscopic and chemical characters of the turquoise are presented in some detail in Part III.

Concerning the origin of the turquoise several opinions have been advanced. Professor Silliman regarded the alteration of the rock as probably due "to the escape * * * of heated vapor of water and perhaps of other vapors or gases, by the action of which the original crystalline structure of the mass has been completely decomposed or metamorphosed, with the production of new chemical compounds. Among these the turquoise is the most conspicuous and important. * * * Chemically it is a hydrous aluminum phosphate. * * * Evidently the decomposition of the feldspar of the trachyte furnished the alumina, while the apatite, or phosphate of lime, which the microscope detects in thin sections of the Cerrillos rock, furnished the phosphoric acid. A little copper ore is diffused as a constitutent of the veins of this region, and hence the color which that metal imparts."

Clarke and Diller considered the turquoise as having replaced veins of apatite. After noting the fibrous structure of the gem, and that the fibers run directly across the vein at right angles to the walls, and are arranged perpendicularly along the sides of small fissures running into or across the vein, they continue: "The perpendicular arrangement of the turquoise fibers along fissures crossing the vein indicates that the mineral may have been derived from the alteration of another substance with which the vein was formerly filled. We would suppose, of course, that the original vein material was itself a phosphate; and the only one after which turquoise is known to be pseudomorphous is apatite, a species which not infrequently occurs in veins. The opinion that the turquoise has resulted from such an alteration is favored by the presence of other alteration products, to be noted in considering the composition of the country rock in which the turquoise is found. It is also suggested by Hermann's analysis of blue Oriental turquoise, in which the equivalent of 3.41 per cent. of calcium phosphate was actually determined."

In 1900 Dr. C. L. Herrick expressed his opinion of the origin of the turquoise in the following words: "The syenite * * * has been intimately blended with fragments or great masses of the sedimentary rocks through which it has broken its way. These rocks were mainly Jura-Triassic and Cretaceous. It would appear from a careful study of the region that the turquoise owes its origin to action of the molten syenite on the copper-bearing sandstone of the Jurassic it had caught up in its escape."*

Concerning the above theories, the following facts may be urged against the latter one, that of an origin in the metamorphic action of molten lava on copper-bearing Jurassic sandstones: It is not clear what reactions would take place between molten lava and a sandstone to produce the turquoise, a non-siliceous mineral. The theory is not supported by any field evidence. The matrix of the turquoise, while resembling sandstone in places, is an altered igneous rock, as all students of this region agree. So far as I was able to find, there is no sandstone in the vicinity of Mt. Chalchihuitl. The inclusions of red sandstones farther east, while resembling the red beds of the Jurassic, are now known to belong to the late Cretaceous or Laramie, and carry no copper so far as observed.

As will appear from the petrographical descriptions in Part III. of this report, tourmaline occurs in the decomposed country rock, and its presence suggests some such action of escaping vapors, gases or waters, as is premised by Silliman. There is every reason to believe that the crushed and sheared zones in the andesite formed passage-ways for the active agents which effected the decomposition. Whether or not the turquoise was formed at that time as one of the new chemical compounds, as is supposed by Silliman, or is a later alteration product from apatite in veins, according to Clarke and Diller, is another question.

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*"Geological Associations in New Mexico Mining Camps," Rep. of Gov. of New Mexico, 1900, p. 258.

If the turquoise represents a replacement of veins of apatite, we should expect to find some trace of the original mineral in some of the numerous sections examined. Apatite, even when occurring in veins, usually but not always shows a greater or less development of the crystalline habit. In the Cerrillos case, no trace of apatite in veins has ever been found, and in no case does the form of the turquoise suggest the outline of some antecedent crystalline mineral. On the other hand, apatite does occur in the country rock as tiny crystals, but so far as seen was never replaced by turquoise.

It does not seem to me necessary to assume the former existence of veins of apatite in the rock in order to explain the existence of the turquoise in its present condition. The appearance under the microscope suggests rather that the gem formed in the crevices directly, as one of the alteration products of the various minerals constituting the country rock. That the alumina of the turquoise was derived from the decomposing feldspar of the andesite, as suggested by others, seems most probable. And it seems equally probable that the apatite, occurring as an accessory mineral in the andesite, furnished the phosphoric acid. The fact that Clarke and Diller failed to find apatite in their sections is not surprising in view of the greatly decomposed character of the specimens examined by them. For while this mineral is usually abundant in all the fresher portions of the rock, sometimes occurring as quite large crystals, it is seldom seen in the more decomposed portions containing the turquoise; which is just what we should expect on the basis of the theory as to origin here supported.

The copper, which Clarke, Diller and others regarded an an impurity, but which according to Penfield is an essential constituent of the mineral turquoise, was probably supplied from the same copper-bearing solutions, possibly indirectly, which gave rise to the copper-bearing ores of the region. In the mines of the American Turquoise Company the copper is found forming a green coating on the walls of the tunnels, etc., wherever the rock is left undisturbed for any length of time.

The intimate association of fluorite with the turquoise is very suggestive. As shown in Part III. of this report, the relations and appearance are what we should expect if the turquoise formed first, leaving the fluorine of the apatite to make fluorite, which latter formed about the turquoise. The proportion of the fluorite to the turquoise is suggestive of the proportion of fluorine to phosphoric acid in apatite, the fluorite being a minor factor as regards quantity.

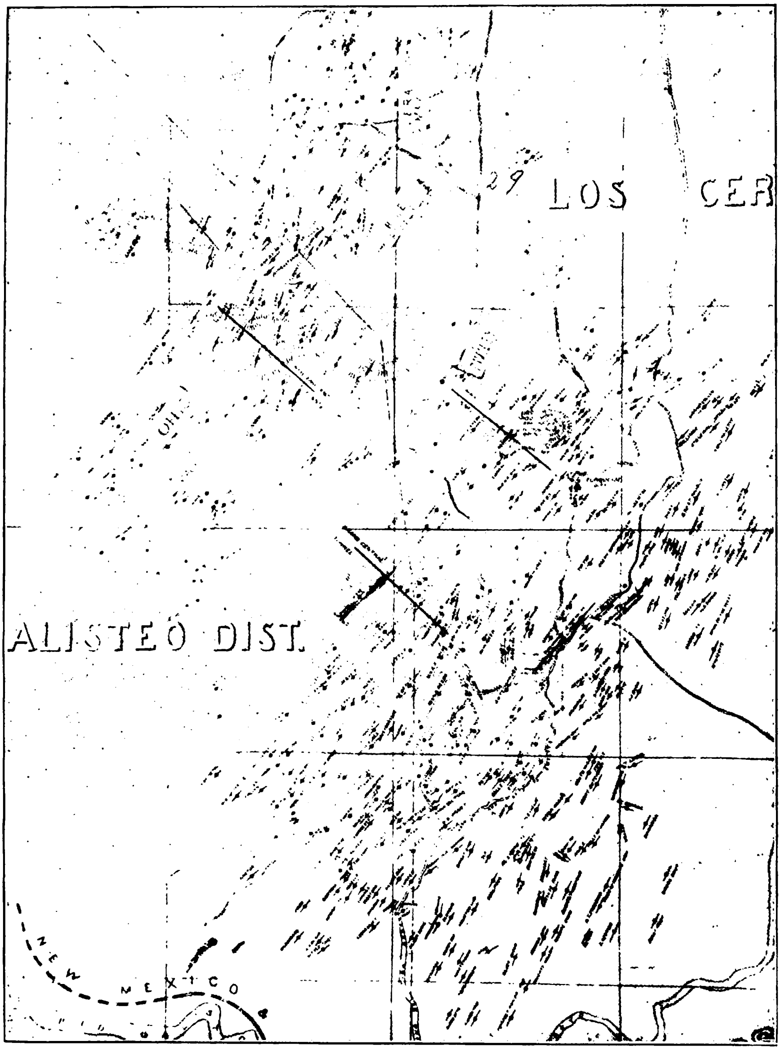
Metallic Minerals.

While the Cerrillos Hills have never produced much in the way of metallic minerals, the region was once the scene of no little mining activity, and every summer still finds a number of active prospectors' camps in operation and perhaps one or two small mines. In the late 70's and early 80's Carbonateville and Bonanza City, now marked only by the ruins of old buildings or by a few Mexican adobes, were booming mining camps.

Prospecting parties spreading southward along the Rockies after the great Leadville excitement overran the mountains of northern and central New Mexico. One of these parties took up claims in the Cerrillos Hills, where were found ruins of mines of great antiquity, evidently worked and then abandoned by the Indians. The news of the numerous northeast and southwest "veins" in these hills soon attracted a goodly company of miners, and the most prosperous days of the Cerrillos region began. Claims were located everywhere on the very numerous mineralized belts, and the hills were fairly honeycombed with small shafts, tunnels and open cuts, most of them of very limited extent. A few enterprises on a larger scale were undertaken, and some ore shipped from the neighborhood of the Cash Entry and Grand Central mines.

The camp was not long-lived, however. Doubtless the early miners found the richness of the veins themselves less seductive than was the number of them. To the fall in the price of silver, the failure of two patent smelter schemes and also of one of the larger mining enterprises is popularly attributed the failure of the camp.

The ores of the Cerrillos region are in the main lead-silver and zinc, carrying a little gold, and more or less copper. At the sur-



PORTION OF OLD MINE MAP OF CERRILLOS HILLS. (The little bars through the dots show the direction of lode in each excavation.)

face the ores are chiefly in the oxidized form, but pass into the sulphides in depth. In most instances the ore occurs in sheared zones having a northeast-southwest trend. The movements producing this extensive shearing have already been referred to. It would seem that the ore-bearing solutions arose along these crushed zones, giving rise to the numerous mineralized belts which attracted the early miners. True fissure veins are also encountered, but are less common. Both shear zones and veins approximate the vertical.

The direction of the strike, as well as the number of these mineralized belts, is well shown by the accompanying reproduction (Plate P) of a portion of one of the old mine maps, which represents the various openings, together with the strike of the ore bodies.

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THE GEOLOGY OF THE CERRILLOS HILLS, NEW MEXICO.

BY DOUGLAS WILSON JOHNSON.

PART II. PALÆONTOLOGY.

INTRODUCTION.

The following report on the Palæontology of the Cerrillos district is based upon a collection of fossils made by the writer during the summer of 1902. So far as I am aware, no fossils have been previously described from this locality, with the exception of a few plant remains from above the coal near Madrid, although brief references to several species of *Ostrea*, *Inoceramus*, etc., were made by the earlier explorers. The region about the Cerrillos Hills is extensively broken and faulted, and the strata are profoundly metamorphosed. As a result, much of the material in the collection is fragmentary, perfectly preserved fossils being rarely found. Fossiliferous horizons are not numerous, and as they are more often found in widely separated localities, in a region broken by many faults, details of correlation, estimates of thicknesses of beds, and other desirable data could not always be secured. In some instances, however, excellent sections were exposed, the barrenness of the country making it possible to trace the succession of the beds without difficulty. These sections are represented in diagrammatic form in Part I. of this report, where a detailed consideration of the stratigraphy will be found.

It has been no part of my plan to present herein a complete bibliography and synonymy of the fossils described. As a rule references are given to other works where such lists, together with detailed descriptions, may be found. It has been my endeavor to refer to those works most easily accessible, unless for special reasons some other reference seemed desirable.

In the preparation of this part of the report on the Geology of the Cerrillos Hills, the writer has profited continually by the advice and suggestions of Professor Amadeus W. Grabau, for whose cordial interest he desires to express his sincere gratitude. I am also under obligations to Mr. Timothy W. Stanton for the opportunity to make comparisons with certain of his types in the National Museum at Washington, as well as for valuable suggestions concerning the identity of some doubtful forms. To Mr. Frank H. Knowlton thanks are due for the identification of the fossil flora of the region, and to Dr. Bashford Dean for the identification of certain fish scales. Mr. J. L. Wells, of Cerrillos, New Mexico, kindly loaned several fossils as noted in the descriptions. To Miss Rena B. Johnson I am indebted for the care and skill bestowed upon the illustrations. Other acknowledgments will be found in the text.

GEOLOGIC DESCRIPTION.

The strata exposed in the Cerrillos district belong to three different periods, the oldest series being that of the Red Beds, the age of which is not known. These beds appear to be wholly barren of fossils. It can only be said that the similar beds in neighboring districts are wholly or in part of Permian or Jura-Triassic age, and, as seen in another part of this report, the evidence in the Cerrillos region indicates that they occupy a similar position here. These beds are exposed below fossiliferous Cretaceous sandstones and shales along the western border of the Cerrillos sheet, in what has been termed the Galisteo Monocline. They are of very considerable but unknown thickness.

The next period represented here is the Cretaceous. The beds consist of massive and loose yellow, gray and red sandstones and calcareous or carbonaceous shales, and occupy a large part of the southern half of the area under consideration. These beds are fairly fossiliferous in places, and a consideration of their faunal relations appears below. In a region so broken and faulted it was not possible to secure accurate estimates of the thickness of the strata, but several typical sections are given in connection with the consideration of the stratigraphy to be found elsewhere in this report.

Resting unconformably upon the strata of the preceding divisions are loose, imperfectly stratified sands of more recent age, which attain a thickness of a hundred feet or more in places. These beds, known as the Santa Fè Marls, are composed of the finer, more distant material in the great alluvial fans which spread out from adjacent mountain ranges, and so far as observed contained no fossils in this region. The deposits represent at least that time interval included between the beginning of the Upper Miocene and the present epoch, and in some regions outside of the Cerrillos district attain a very great thickness. By the earlier geologists all of these beds were referred to the Tertiary. A detailed discussion concerning them will be found in Part I. of this report.

CORRELATION OF THE CRETACEOUS.

The following subdivisions of the western Cretaceous are generally recognized:

Laramie.	
Fox Hills Fort Pierre	Montana.
Niobrara Fort Benton	Colorado.
Dakota.	

All of the fossiliferous beds in the Cerrillos district belong to the Colorado and Montana formations, with the possible exception of the red sandstones of the Galisteo Group, in which fossil tree trunks are found, and which may be of Laramie age. If the Dakota is present, as seems most probable, it only appears at the extreme western edge of the district under consideration, in the Galisteo Monocline. At the very top of the monocline were found beds of Colorado age, below which there is a considerable thickness of yellow and gray sandstones under which are seen the Red Beds. It is probable that these yellow and gray sandstones belong to the Dakota, although I have no faunal evidence.

Cerrillos Section.

The fossils belonging to the Colorado group all come from two localities — one of which is a few rods northeast of the smelter, just north of the town of Cerrillos. Almost in contact with the intrusive mass at this point was exposed a small bed of dark, calcareous shales, striking N. 45 W. and dipping 25 N., or in toward the intrusive. This represents one of the groups of strata which are found in close proximity to the laccolith, dipping in toward it, the beds a little further removed usually dipping sharply away from the center in all directions. From these shales the following fossils were collected:

(An interrogation point before the name indicates that the identification was made with some doubt.)

Ostrea lugubris Conrad.
Inoceramus labiatus Schlotheim.
I. dimidius White.
I. fragilis H. & M.
Scaphites warreni M. & H.
Prionocylus macombi Meek.
P. wyomingensis Meek.
P. sp. nov.
Prionotropis woolgari Mantell.
Rostellites dalli var. *wellsi* var. nov.
? *R. ambigua* Stanton.
Acmæa cerrillosensis sp. nov.
Scurria? coniformis sp. nov.
Aucella strongi sp. nov.
Beryx sp. undet.

In his paper on the Colorado formation Stanton gives the following list of species which are not known to range above the Colorado, and are all sufficiently abundant and widespread to be of use in correlation:

Ostrea lugubris,
Exogyra columbella,
Gryphæa newberryi,
Avicula gastrodes,
Gervillia propleura,
Inoceramus labiatus,
I. dimidius,
I. fragilis,
I. umbonatus,
I. exogyroides,
I. deformis,
I. undabundus,
Cardium pauperculum,
Liopistha (*Psylomya*) *meeki*,
L. (*P.*) *concentrica*,
Turritella whitei,
Glauconia coalvillensis,
Pugnellus fusiformis,
Baculites gracilis,
Buchiceras swallovi,
Scaphites warreni.
Prionocyclus,
Prionotropis,
Mortoniceras.

Of the last three genera no species have been found above the Colorado formation in America.

An examination of the list of fossils reported from the shales just north of Cerrillos, as given above, shows that of the fifteen species recorded, the first nine belong in the list of forms given by Stanton as characteristic of the Colorado formation. The next two were also found in the same formation at different points in Colorado, while the last four, with the exception of the fish scales referred to *Beryx*, are new. That these shales are of Colorado age is thus established beyond question. As the exposure was small and the shales crushed and broken, no satisfactory further division could be made; any distinction such as that between the Niobrara and Fort Benton was impracticable, if indeed anything higher than Upper Fort Benton was represented.

Section Southwest of Santa Rosa Mountain

Two miles southwest of Santa Rosa Mountain, where the main wagon road leaves the basalt-capped mesa for the valley below, there are exposed in the valley at the foot of the mesa fossiliferous shales and sandstones. The exposure is not large, but a small arroyo has removed some of the looser shales, leaving still in place the calcareous nodules in which the fossils are most abundant.

The following species were collected at this locality:

?? *Ostrea congesta* Conrad.
? *Protocardia rara* E. and S.
Astarte evansi H. and M.
Nucula subplana M. and H.
? *Solen cuneatus* Gabb.
Lingula subspatulata H. and M.
Tritonium kanabense Stanton.
Natica sp. undet.
Baculites anceps Lamarck.
? *Helicoceras pariense* White.
Beryx sp. undet.
? *Arca madridensis* sp. nov.
Cyprimeria ? sulcata sp. nov.
Turritella galisteoensis sp. nov.
Admetopsis ? elevata sp. nov.

Of the above fifteen species, *Astarte evansi*, so far as the writer is aware, is restricted to the upper Fort Pierre; while *Nucula subplana* has only been found in beds containing a mingling of Upper Fort Pierre and Fox Hill species. *Protocardia rara* was also found at the latter horizon. Of the new species, *Arca madridensis* is found elsewhere associated with *Inoceramus vanuxemi*, a characteristic Fort Pierre type. *Cyprimeria ? sulcata* is found elsewhere associated with *Astarte evansi* and *Inoceramus vanuxemi*, in beds of Upper Fort Pierre age; while in other localities it occurs with *Inoceramus balchii*, another Upper Fort Pierre type. *Turritella galisteoensis* was not found elsewhere with any fossil whose range is already known, but occurs with *Arca madridensis* and *Cyprimeria ? sulcata* in beds most probably of Fort Pierre age.

The only one of whose identity we are certain of the fifteen species that might occasion any doubt is *Tritonium kanabense* Stanton. This species occurs about 350 feet above the base of the Cretaceous section of the Upper Kanab valley in Utah, in beds which Stanton correlates with the lower part of the Colorado formation. It is very possible to conceive, however, that this form might range up into the Fort Pierre, while it is not possible to conceive that the other evidence will admit of anything but a Fort Pierre age for these beds. That the horizon is Upper Fort Pierre, is indicated by several of the fossils.

Madrid Section.

The Madrid section, a diagram of which will be found in another part of this report, was made along a nearly east and west line passing through the town of Madrid, and was about a mile and a half in length. This section shows an easterly dipping series of sandstones and shales, wlth several intrusive sheets of lava. At the base of this section, about a mile west of Madrid, are found beds of yellow and white sands, overlain by one of the intrusive sheets, as follows:

Intruded sheet of lava.	
Massive sandstone	30 feet
Shaly "	6 "
Massive "	6 "
Shaly "	40 "
Shaly " with concretions	30 "
(Small hiatus.)	
Loose sands with concretions,	50 "

The lower eighty feet of this section were fossiliferous, the fossils gathered being mostly weathered out, probably from the concretions. As, with the exception of one stratum, no fossils could be found in place, no detailed separation of these lower eighty feet could be made on a faunal basis. The best exposures were along a steep hillside, toward the foot of which the concretions and fossils had washed down, although a few specimens were found well toward the top. Just above the lower fifty feet of loose sands was a thin stratum made up almost entirely of *Ostrea anomioides* var. *nanus*.

The following forms were collected from this horizon:

Inoceramus simpsoni Meek.
I. cripsii var. *barabini* Morton.
I. vanuxemi M. and H.
I. sp. undet.
Placenticeras placenta (Dekay).
? Stantonoceras guadaloupæ (Roemer).
Baculites, sp. undet.
Ostrea anomioides var. *nanus* var. nov.
Endocostea brooksi sp. nov.
Arca madridensis sp. nov.
Placenticeras ? intermedium sp. nov.
P.? rotundatum sp. nov.

Of the above twelve species (of which the last five are new) *Inoceramus vanuxemi*, so far as the writer is aware, does not occur above the Fort Pierre. Certainly it is a characteristic Montana form, not occurring below that formation. On the other hand, *Inoceramus simpsoni*, while ranging lower, has not been found above the Fort Pierre. Of the new forms *Ostrea anomioides* var. *nanus* is found elsewhere associated with *Inoceramus vanuxemi*, while we have already seen that a form probably belonging to the species *Arca madridensis* occurs in association with *Astarte evansi* and other Fort Pierre types. *Inoceramus cripsii* var. *barabini* is a good Fort Pierre fossil, but identical or closely similar forms range much higher. The remaining forms offer no conclusive evidence. That the fauna shows a Fort Pierre age, there can be no doubt.

Half a mile east of Madrid, at the top of the Madrid section, the following succession is found, given in descending order:

Loose sand (upper part concealed)	Several	feet.
Intruded lava sheet	1	"
Soft sandstone	8	"
Intruded lava sheet	3	"
Soft sandstone	10	"
More indurated sandstone	9	"
Carbonaceous shales	10	"
Sandstone	6	"
Intruded lava sheet	8–10	"
Shales	3–4	"
Coal seam	2	"

In the nine-foot band of more indurated sandstones were numerous impressions of leaves and fruits, mostly fragmentary. The following species were identified by Mr. F. H. Knowlton from a small collection made by the writer:

Ficus rhamnoides Knowlton.	*Aralia?* sp.
F. uncanta Lesquereux.	

Of the above species *Ficus rhamnoides* is only known from the Fox Hills beds at Point of Rocks, Wyoming. The next species has been reported from beds referred by Lesquereux to the Tertiary. But the only collections made from these beds were those made by the Hayden Survey many years ago, at which time Lesquereux referred practically everything in the Fox Hills to the Tertiary. No further evidence as to the age of these beds has been forthcoming, but the conviction has been growing in the minds of many that they are not Laramie, as now understood, but Montana.

It would seem, then, that the evidence of the plants from the coal measures at Madrid indicates a Fox Hills age for the beds at that point. I quote the following from a letter I received from Mr. Knowlton, written on the second of February last:

" Now as to the probable age as indicated by your fossils. I am strongly of the opinion that it is Upper Montana, or, if you please, Fox Hills. Point of Rocks, whence came the *Ficus rhamnoides*, is now known to be of this age, and the other species has not been found in what we now know to be true Laramie."

Reference to Part I. of this report will show that I have there set forth in detail a discussion of the stratigraphical relations of these beds. On the basis of the stratigraphical evidence alone I would have no hesitation in referring the coal to the Fox Hills, and in fact did so refer it after my earlier work in the region. With the corroborative evidence of the plant remains, we may consider the Fox Hills age of the beds established beyond any doubt. The opinions of the earlier geologists, and the evidence upon which their opinions were based, will be found in connection with the more detailed discussion above referred to.

Achavica Arroyo Sections.

One mile northwest of Grand Central Mountain, in Achavica Arroyo, are exposed a series of sandstones and shales, dipping sharply away from the intrusive core of the main uplift, with which these beds are in contact at the eastern end of the section. At the western end the section is terminated by a fault, beyond which the beds dip toward the east, apparently away from a smaller intrusion of the lava a few rods farther west. The whole formation is profoundly metamorphosed, and the strike and dip vary considerably, the average being about N. 40 E. for the former and 50 W. for the latter.

The following beds are exposed, given in descending order:

[Fault cutting off section at western end (top).]	
A. Sandstones and shaly sands	60 feet.
B. Sandstones and shaly sands	40 "
Small dyke or sheet of the intrusive.	
C. Shaly sands D. Shaly sands	40 "
E. Sandstones and shaly sands	30 "
F. Mostly shales	20 "
Intrusive core of main uplift.	

The above thicknesses are only approximate, exact measurements being impracticable. A few fossils were found in each of the divisions, as recorded below.

A.

Ostrea anomioides var. *nanus* var. nov.
Inoceramus vanuxemi M. and H.
? *Trigonarca obliqua* Meek.
Rostellaria ? texana Conrad.

B.

? *Endocostea typica* Whitfield.
Cyprimeria ? sulcata sp. nov.
? *Protocardia rara* E. and S.
Baculites anceps Lamarck.

C.

Cyprimeria ? sulcata sp. nov.
? *Protocardia rara* E. and S.
Corbula nematophora var. *fitchi* var. nov.

D.

Inoceramus balchii M. and H.
I. irregularis sp. nov.
Cyprimeria ? sulcata sp. nov.

E.

Inoceramus balchii M. and H.
Ammonites sp.

F.

Ammonites sp.

In several of the above divisions were found many specimens of *Inoceramus* too fragmentary for identification. The ammonites in E and F were represented by small fragments of the outer whorl, and were apparently identical with some of the Fort Pierre types found at the base of the Madrid section, such as *Placenticeras ? rotundatum* or *P. ? intermedium.*

Inoceramus vanuxemi and *I. balchii* are good Fort Pierre types. *Endocostea typica* is only known from the Fort Pierre. *Ostrea anomioides* var. *nanus* was found elsewhere with Fort Pierre forms, as was also *Cyprimeria ? sulcata.* ? *Protocardia rara* occurs in the Fort Pierre beds southwest of Santa Rosa Mountains. So far as the writer knows *Trigonarca obliqua* has not been recorded from the Fort Pierre, but it has been found not far below its base. It may range up into Fort Pierre beds, or, as shown by the interrogation point, the form found in the above locality may possibly not be identical with it. *Baculites anceps* seems to have a rather extensive range. The remaining forms indicate the Fort Pierre age of the beds.

Some distance farther south in the Arroyo and one mile west of Grand Central Mountain, are found several hundred feet of shales rich in concretions, which vary in dip from 20–25° E. to vertical. These shales are profoundly altered, being in contact with the intrusive mass at the east. The following fossils were gathered at the western end of the section, where they are usually found in the concretions.

?? *Ostrea congesta* Conrad.
Arca madridensis sp. nov.
Cyprimeria ? sulcata sp. nov.
Turritella galisteoensis sp. nov.

A number of other forms were secured, but were so fragmentary and altered that not even provisional identifications could be made. As the above three species (concerning whose identity we are sure) are all of them new, and constitute the only evidence we have as to the age of the beds, it is evidently impossible to give any definite opinion regarding this point. The fact that wherever else these species have been found in the region they have been associated with Fort Pierre types, makes it appear probable that these beds belong to the Fort Pierre group. Such evidence alone, however, cannot be considered conclusive.

Section Northwest of Waldo.

Near the wagon road, three miles northwest of Waldo, a few fossils were collected which had weathered out of the shales over which the road passes. There is no definite exposure of these shales at this point, and the fossils were found lying on the surface, usually where large concretions had broken apart but resisted the weathering which removed the lighter shales. It will be understood, then, that no definite horizon for the occurrence of these forms can be given. The following species were represented:

Inoceramus labiatus Schlotheim.
? *Astarte evansi* H. and M.
Stantonoceras pseudocostatum sp. nov.
Placenticeras placenta Dekay.
P. sp. undet.
Baculites anceps Lamarck.

Inoceramus labiatus is regarded as characteristic of the Colorado formation. *Astarte evansi*, on the other hand, is characteristic of the Montana. A single impression was referred to that species with an interrogation point, although it seemed to the writer that the reference was most probably correct. The form of *Placenti-*

ceras placenta found here is the large variety which seems closely similar to the New Jersey forms. As said before, the range of *Baculites anceps* seems rather extensive. The ancestral types of *Stantonoceras pseudocostatum* are found in the Fort Pierre. It is apparent then that nothing definite can be said with regard to the age of these beds, especially when there is the possibility for a mingling of faunas from widely different horizons such as exists at the locality in question. No assumptions can be based upon material collected in such a manner as these forms necessarily were, beyond that which the fossils themselves indicate—that the collection probably represents a mingling of faunas weathered out from beds of different ages.

Galisteo Monocline Section.

A mile or more west of the above locality, just south of the wagon road, are exposed easterly dipping shales which form the most eastern exposure of the Galisteo Monocline. About one hundred feet of these shales are shown between interbedded sheets of lava, and from them the following fossils were collected:

Ostrea lugubris Conrad.
? *Astarte evansi* H. and M.
Inoceramus sp. undet.

Since the species *Ostrea lugubris* was quite abundant, and is regarded as characteristic of the Colorado formation, it is probably safe to regard these shales as of Colorado age. The specimens doubtfully referred to *Astarte evansi* may possibly be a distinct species.

Section Near San Marcos Reservoir.

About one half mile west of the reservoir in San Marcos Arroyo, and in a branch of that arroyo, was found a large mass of shales and sandstones apparently surrounded by the eruptive. These beds were naturally much altered, but the following forms could be identified:

Inoceramus vanuxemi M. and H.
Cyprimeria? *sulcata* sp.nov.
Astarte evansi H. and M.
? *Tritonium kanabense* Stanton.
Baculites sp. undet.

The occurrence of the first three forms leaves little or no doubt but that the beds here represented are of Fort Pierre age. As seen in a preceding section, *Tritonium kanabense* occurs in beds containing an undoubted Fort Pierre fauna.

Grand Central Mountain Section.

On the western slope of Grand Central Mountain, and well toward the summit, there was found an inclusion of shales an acre or less in extent, completely surrounded by the intrusive. These shales were fairly rich in specimens of *Inoceramus*, none of which it was possible to identify, so fragmentary and altered were they.

Section East of Cerrillos.

Beginning about a mile east of Cerrillos, and extending a mile or more further eastward, is exposed a great thickness of easterly dipping sandstones. The lower portion of these beds is composed of yellow and gray sandstones, overlying the coal measures and apparently conformable with them. A careful search revealed no fossils in any part of this series. The upper portion of these beds consists of deep red sandstones, which so closely resemble the sandstones of the "Red Beds" proper that considerable discussion as to their age has resulted. There is no evidence of any fault which might bring the Red Beds up above the Cretaceous at this point, however, and the beds in question seem to lie conformably upon the undoubted Cretaceous below. In one place in this group, which Hayden has called the Galisteo Group, fossil tree trunks are abundant, and an examination of thin sections of one of these by Mr. Knowlton proved it to be a highly organized dicotyledon, wholly unlike anything known from the Red Beds, but of evident Upper Cretaceous (or later) affinities. The tree was regarded as very probably belonging to the genus *Quercus*.

It seems most probable, then, that the Galisteo Group is of Upper Fox Hills or Laramie age. A full discussion of the stratigraphic relations will be found in Part I. of this report.

DESCRIPTION OF SPECIES.

MOLLUSCOIDEA.

BRACHIOPODA.

Lingulidæ.

Genus LINGULA Bruguière.

LINGULA SUBSPATULATA H. and M. (Pl. I., Fig. 11, *a*, *b*.)

For description and synonymy see Rep. Geog. and Geol. Expl. west of 100th Mer., Vol. IV., Pt. I., p. 169.

Of this species I have one example from the Cerrillos region, and several from a locality a few miles southeast of the area properly under discussion. The specimen from the Cerrillos district was found in the shales southwest of Santa Rosa Mountain, the shell itself being preserved, except the upper portion about the beak. Its perfect agreement with the description of the type leaves no doubt as to its identity.

Locality and Position.—Near wagon-road just south of basalt-capped mesa, two miles southwest of Santa Rosa Mountain, in shales of Fort Pierre age. The more perfect specimens, one of which is also figured, were collected from the clay beneath the coal at the most northern of the coal mines east of the Ortiz Mountains owned by the Santa Fé Gold and Copper Company. (Col. Univ. Coll. Pal., No. 14960, *a*, *b*.)

MOLLUSCA.

PELECYPODA.

Ostreidæ.

Genus OSTREA Linnæus.

OSTREA ANOMIOIDES var. NANUS var. nov. (Pl. I., Fig. 10, *a*, *b*, *c*, *d*.)

For description and synonymy of *Ostrea anomioides* Meek, see Bull. U. S. G. S., No. 106, p. 55.

Shell small, thin, depressed plano-convex, ovate or circular in outline; usually a little straightened along cardinal margin; no scar of attachment visible. Lower valve rather shallow, beak a little elevated and scarcely projecting beyond cardinal margin; muscular scar subreniform, quite distinctly impressed, subcentral; upper valve nearly flat, muscular scar indistinct. Cartilage pits obscure. Surface of both valves ornamented with concentric wrinkles, most prominent on the upper valve; fine radiating striæ seen near anterior margin of a few lower valves.

Greatest diameter of average specimen, 13 mm.; breadth, 10–13 mm.; convexity, 3 mm.

This delicate shell occurs in great abundance at one horizon exposed a mile west of Madrid, making up the greater part of a stratum several inches in thickness. The specimens seem to compare fairly closely with Meek's description of *O. anomioides*, except that they are decidedly smaller, probably representing a dwarfed variety of that species. In his description Mr. Meek does not refer to the fine radiating striæ, but the figure of the lower valve of his type specimen given by White in the Twelfth Annual Report of the U. S. Geol. and Geog. Surv. of the Territories, shows that such striæ existed.

Locality and Position.—One mile west of Madrid in sandstones of Fort Pierre age. Also in Achavica Arroyo, one mile northwest of Grand Central Mountain, in strata of same age. (Col. Univ. Coll. Pal., No. 14961.)

? OSTREA CONGESTA Conrad.

For description and synonymy see Bull. U. S. G. S., No. 106, p. 55.

In the beds southwest of Santa Rosa Mountain there is one thin stratum which is made up almost entirely of a species of *Ostrea.* The beds are so metamorphosed, however, that it was impossible to secure any specimens capable of being positively identified. It is quite evident that the forms were extremely variable, but they bear a general resemblance to Conrad's species.

Locality and Position.—Near wagon road just south of basalt-capped mesa, two miles southwest of Santa Rosa Mountain, in strata of Fort Pierre age. Also found in the beds of same (?) age in Achavica Arroyo, one mile west of Grand Central Mountain. (Col. Univ. Coll. Pal., No. 14962.)

OSTREA LUGUBRIS Conrad.

For description and synonymy see Bull. U. S. G. S., No. 106, p. 58.

This extremely variable species is well represented in the Cerrillos region. Our specimens show nearly every variety of form we have seen figured, and vary in size from those measuring 11 mm. from beak to base to others twice as large. The outline varies from almost circular to subovate or subtriangular. The radiating plications seem to be more compressed and elevated in some of our specimens that in any we have seen figured. Reniform muscular scars are deeply impressed in some individuals, less prominent in others.

Locality and Position.—A few of our specimens came from the Fort Benton shales just north of the town of Cerrillos, but the greater number were secured at the top of the Galisteo Monocline south of the road, several miles west of Cerrillos, in strata of same age. (Col. Univ. Coll. Pal., No. 14963.)

Aviculidæ.

Genus INOCERAMUS Sowerby.

INOCERAMUS FRAGILIS H. and M. (Pl. II., Fig. 17.)

For description and synonymy see Bull. U. S. G. S., No. 106, p. 76.

One poorly preserved internal mold of a right valve from the metamorphosed shales just north of the town of Cerrillos, is referred to this species. The shell is higher than long, with anterior side vertically truncate; the beak is pointed, curves inward and forward, and rises but little above the hinge-line. Obscure traces of concentric undulations still remain.

Locality and Position.—Just north of Cerrillos, in shales of Fort Benton age. (Col. Univ. Coll. Pal., No. 14964.)

INOCERAMUS LABIATUS Schlotheim.

For description and synonymy see Bull. U. S. G. S., No. 106, p. 77.

In the collection from the shales north of Cerrillos there is one specimen, a part of a right valve, which so closely resembles the specimen figured on Plate XIV. of Stanton's paper that it might be considered the original of his Fig. 2; while a left valve from northwest of Waldo, might be the complement of his Fig. 4, Pl. X. Associated with the former were a large number of specimens which might be the elongated forms of the latter type, but which are too poorly preserved to be determined with certainty.

It seems to the writer that these two forms are specifically distinct, but until they are studied from the standpoint of their phylogeny the opinion of those most familiar with the forms should be deferred to.

Locality and Position.—North of the town of Cerrillos, in shales of Fort Benton age. Also near wagon road, three miles northwest of Waldo, associated with *Baculites anceps* and *Stantonoceras pseudocostatum.* (Col. Univ. Coll. Pal., No. 14965.)

INOCERAMUS DIMIDIUS White. (Pl. II., Fig. 18.)

For description and synonymy see Bull. U. S. G. S., No. 106, p. 78.

Of this small species I have three specimens, one right and two left valves. They agree fairly well with the revised description quoted in Stanton's paper, but as a few additional points are noted the following is also given:

Shell very small, gibbous, obliquely subovate in outline; hinge-line short and straight; anterior margin subtruncate above, sloping abruptly backward below and rounding gradually into basal margin; posterior margin rounding from hinge-line gradually and regularly into basal margin, the latter being regularly convex; beaks small, pointed, incurved, inclined forward, situated close to anterior margin, and projecting but slightly above cardinal margin. Surface ornamented with regular, subangular, concentric ridges, separated by moderately wide concave interspaces; also by concentric lines between the ridges, which may not be preserved.

The two most perfect valves in the collection are a little smaller than those figured in Stanton's paper, and do not preserve the finer lines above referred to. The third valve is larger, and retains the more delicate markings, but is badly broken. It is to be noted that the rather prominent angle occurring about one third of the way down the anterior margin of our specimen, is represented in Fig. 5 of the above bulletin as occurring on the posterior margin; while the more evenly rounded outline is that of the posterior margin in our form, but that of the anterior margin in the former.

Locality and Position.—Just north of the town of Cerrillos in shales of Fort Benton age. (Col. Univ. Coll. Pal., No. 14966.)

INOCERAMUS SIMPSONI Meek.

For description and synonymy see Bull. U. S. G. S., No. 106, p. 79.

Of this species I have only the portion of a left valve, but the large size, great length, subtruncate posterior margin, and long, straight hinge-line leave no doubt as to its identity. The concentric undulations are moderately distinct, regular, and separated by moderately wide interspaces. When complete, the height of the shell must have been something over four inches.

Locality and Position.—One mile west of Madrid, in loose sands of Fort Pierre age. (Col. Univ. Coll. Pal., No. 14967.)

INOCERAMUS VANUXEMI M. and H. (Pl. III., Fig. 19.)

For description and synonymy see Rep. on Geol. of Black Hills of Dakota, p. 396.

To this species a number of fragments are referred, one of which is figured on Plate III. This specimen is from Achavica Arroyo, a mile northwest of Grand Central Mountain, and preserves traces of the finer lines between the concentric ridges, some eight or nine such lines occurring between the crests of any two ridges toward the outer margin of shell.

Other examples from same locality show the character of the prominent subangular ridges, and the broader concave interspaces.

Locality and Position.—Besides the one figured, several other specimens from the same locality are referred to this species. These occur in hard, metamorphosed sandstones of Fort Pierre age. At the base of the Madrid section were found two specimens, in loose sands of the same age, while in the inclusion of sands and shales caught up in lava half a mile west of the reservoir in San Marcos Arroyo there was found one fragment referred doubtfully to this species. (Col. Univ. Coll. Pal., No. 14968.)

INOCERAMUS BALCHII M. and H. (Pl. II., Fig. 16.)

For description and synonymy see Rep. U. S. G. S. Terr., Vol. IX., p. 56.

Of this species I have but two examples. They agree in general with Meek's description given in above reference, but seem to be a somewhat less accelerated type. The concentric undulations are more pronounced, and extend further out toward margin of shell.

To Meek's description the following may be added: In addition to the concentric undulations, the surface is ornamented with fine concentric lines, especially well shown in the concave interspaces between the ridges. Also, along hinge-lines at least, traces of faint radiating lines.

Locality and Position.—Achavica Arroyo one mile northwest of Grand Central Mountain, in strata of Fort Pierre age. (Col. Univ. Coll. Pal., No. 14969.)

INOCERAMUS CRIPSII var. BARABINI Morton. (Pl. V., Fig. 22.)

For description and synonymy see Rep. U. S. G. S. Terr., Vol. IX., p. 49.

The right valve figured on Plate V. is referred to this species as figured and described by Meek in the above cited reference. It is the only example of this species occurring in the collection, and was found in the loose sands at the base of the Madrid section, associated with such forms as *I. simpsoni*, *Endocostea brooksi*, *Ostrea anomioides* var. *nanus*, etc. The shell is about 45 mm. in height, and shows fine concentric lines of growth between the somewhat worn, regular undulations.

Locality and Position. — One mile west of Madrid in loose sands of Fort Pierre age. (Col. Univ. Coll. Pal., No. 14970.)

INOCERAMUS IRREGULARIS sp. nov. (Pl. IV., Fig. 21, *a*, *b*.)

Shell rather large, subovate, very gibbous, the greatest convexity being in the antero-dorsal region; length (apparently) about one and one half times as great as height; anterior end narrower than posterior; ventral margin rounding obliquely upward toward anterior margin; posterior margin unknown; hinge-line long and straight; beak (absent) situated well toward anterior end. Surface ornamented with prominent, extremely irregular extravagantly developed concentric ridges, separated by rather narrow interspaces; finer markings not shown. Height 85 mm.; convexity left valve, 25 mm.; exact length not known, but not greater than 130 mm.

Although this species is only known from the internal mold of a portion of a left valve, its specific characters are so pronounced as to render future identification of similar types practicable. Even in its fragmentary condition it is readily distinguished from *I. simpsoni* or *I. oblongus*, which the portion still remaining most resembles, by the absence of subtruncate posterior margin (as indicated by the concentric ridges), and also in the case of *I. simpsoni*, by the evident greater width as compared with length.

Locality and Position. — Achavica Arroyo, one mile northwest of Grand Central Mountain, in sandstones of Fort Pierre age. (Col. Univ. Coll. Pal., No. 14971.)

INOCERAMUS sp. nov. ? (Pl. III., Figs. 20, *a*, *b*.)

There are in the collection internal molds of both valves of an *Inoceramus*, still united, and with a small portion of the shell still adhering along the hinge-line. As the outline of the shell is not preserved in either case, I have thought best not to establish a new species, although the specimen appears to differ from anything I have seen described. The following incomplete description is given:

Shell of medium size, only moderately convex, umbones broad and flat; outline probably subovate, length greater than height; hinge-line long and straight; beaks incurved, projecting but slightly beyond cardinal margin. Surface ornamented with more or less regular, small, low concentric undulations. Convexity of right valve, 7 mm.

Locality and Position. — One mile west of Madrid, in loose sands of Fort Pierre age. (Col. Univ. Coll. Pal., No. 14972.)

INOCERAMUS sp. undet.

Inoceramus is probably the most abundant species found in this region. But since the strata are usually greatly metamorphosed, the fossils contained in them are generally so crushed or altered that few good individuals are to be found. Hence it is that although a large number of specimens of *Inoceramus* were collected, comparatively few admitted of identification, while many remain whose specific character it is impossible to determine.

On the western slope of Grand Central Mountain, and well up the mountain side, there was found an inclusion of shales, caught up and completely surrounded by the eruptive. These shales were rich in several species of *Inoceramus*, but were so profoundly altered that not one of the specimens would admit of even reasonably certain identification. As no other fossils were found, no clue as to the definite age of these shales could be obtained.

In addition to these fragmentary specimens there were found in the shales just north of the town of Cerrillos a number of poorly preserved forms of very small size which might be the young of *Inoceramus*.

Genus ENDOCOSTEA Whitfield.

? ENDOCOSTEA TYPICA Whitfield.

For description and synonymy see Rep. Geol. Black Hills of Dakota, p. 403.

Two impressions of *Endocostea* in the collection are referred to Whitfield's species with some doubt, as only a small portion of the impression remains in each case. Judging from the character of the concentric undulations, and the distinct sulcus, however, the reference is probably correct.

Locality and Position.— Achavica Arroyo, one mile northwest of Grand Central Mountain, in sandstone of Fort Pierre age. (Col. Univ. Coll. Pal., No. 14973.)

ENDOCOSTEA BROOKSI, sp. nov. (Pl. V., Fig. 23, *a*, *b*.)

There are a few specimens of *Endocostea* in the collection which differ markedly from any species hitherto described. Unfortunately in none of the cases is the form entirely preserved, although the specific characters are well enough shown, it is believed, to enable the identification of similar types without difficulty.

The entire shell was only moderately large, irregularly suborbicular in outline, gibbous, the greatest convexity being midway between beak and base; length probably a little greater than height; anterior margin making an angle of about 90 degrees with the hinge-line, and rounding gradually backward toward base; hinge-line long and straight; remainder of marginal outline not preserved. Beaks depressed, slightly incurved, projecting a little above hinge-line, and placed near anterior margin.

Surface ornamented with concentric folds or ridges, which may be considered in two classes; the first ten or twelve being small, rather low, and close together, and extending to where the shell attains its maximum convexity; the last four or five being large, extravagantly developed, situated far apart, and extending from the line of maximum convexity rather abruptly downward to the base of the shell. When seen in profile the shell presents two distinct slopes, making a rather marked angle with each other, the one ornamented with the smaller, closely arranged ridges, the other with the large, extravagantly developed series. These two series do not grade one into the other, but the change is as sudden and complete as that of the angle in slope. In addition to these folds or ridges there are fine concentric lines of growth.

Oblique sulcus strongly marked, narrow and pointed toward the beak, but widening and deepening posteriorly; concentric ridges distinctly crossing this sulcus.

The character of ornamentation and the relation of the same to the prominent angle made by the two different slopes on the shell will readily distinguish this species, which is named after Mr. Herbert O. Brooks, who accompanied the writer during some of his earlier work in this region.

Locality aad Position.—One mile west of the town ot Madrid, in loose sands of Fort Pierre age. (Col. Univ. Coll. Pal., No. 14974)

Genus AUCELLA Keyserling.

AUCELLA STRONGI, sp. nov. (Pl. I., Fig. 1, *a*, *b*, *c*, *d*, *e*.)

Shell small, inequivalve, convex, high and narrow. Left valve with beak prominent and very strongly incurved, placed along anterior margin, and directed so distinctly forward as to give it a spiral form; posterior ear well extended and strongly marked; hinge-line long and straight; a prominent, subtriangular, concave area is bounded on one side by the hinge-line, on another by the posterior ear, with which it makes a distinct angle, while on the third side the area is truncated by the anterior surface of the shell; anterior portion (at least) of area marked by transverse striæ. Right valve (only one poor example seen) apparently less convex; beak very much less prominent, small and pointed; byssal groove and notch not shown. Surface of both valves marked by low, ill-defined concentric undulations, and fine, obscure radiating striæ, the latter sometimes being obsolete.

Extreme length of average specimen, 24 mm.; extreme breadth, 18 mm.; convexity, 10–12 mm.

This species may be readily distinguished from the forms described by Stanton and others from the Pacific coast by its more prominent posterior ear and well developed adjacent subtriangular area, its more incurved beak, and the great convexity of the shell. The area is even more prominent than that shown in Fig. 9, Pl. III., of Lahusen's monograph "Ueber die Russischen Aucellen," * while the transverse striæ were quite noticeable on one specimen, and are possibly analogous to the radiating striæ on the rest of the shell. The species is named after Dr. O. S. Strong, who accompanied the writer in the field.

Locality and Position.—Just north of the town of Cerrillos, in shales of Fort Benton age. (Col. Univ. Coll. Pal., No. 14975.)

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* "Mém. du Comité geologique," Vol. VIII., No. 1, St. Petersburg, 1888.

Arcidæ.

Genus ARCA Lamarck.

ARCA MADRIDENSIS sp. nov. (Pl. I., Fig. 2.)

Shell small, convex, longer than wide; beaks quite prominent, incurved, inclined forward, situated anterior to the middle; cardinal margin almost as long as shell; anterior margin rounded, sloping obliquely back toward ventral margin; posterior margin subtruncate; ventral margin rounded in front, rather straight behind, approximately parallel with hinge; area long and narrow.

Surface ornamented with from 20 to 24 prominent, simple, radiating costæ, increasing in width toward margin, and making the latter beautifully crenulate. Dentition very obscure, apparently that of *Arca.*

Length of type specimen 10 mm.; height 7 mm.; convexity of single valve 2.5 mm.

Of this species I have but two left valves, and one badly distorted right valve, the latter of doubtful identity. The type specimen is well preserved, except that the dentition is obscured by the matrix, from which it seems impossible to separate the shell with safety.

Locality and Position.—The type came from one mile west of Madrid, in sandstone of Fort Pierre age. The other left valve came from the Fort Pierre (?) shales in Achavica Arroyo, one mile west of Grand Central Mountain, and the right valve from near wagon road just south of basalt-capped mesa two miles southwest of Santa Rosa Mountain, in shales of the same age. (Col. Univ. Coll. Pal., No. 14976.)

Genus TRIGONARCA Conrad.

? TRIGONARCA OBLIQUA Meek.

For description and synonymy see Bull. U. S. G. S., No. 106, p. 92.

There are two internal molds of *Trigonarca* in the collection which I believe belong to this species; they have been so crushed as to render absolute identification impossible. The imprints of the concentric lines of growth have been impressed on the molds, and their non-conformity along several fracture lines shows that the specimens were subjected to considerable distortion. They agree so closely with the original description in most points, however, that the reference is probably correct.

Locality and Position. — Achavica Arroyo, one mile northwest of Grand Central Mountain in sandstone of Fort Pierre age. (Col. Univ. Coll. Pal., No. 14977.)

Nuculidæ.

Genus NUCULA Lamarck.

NUCULA SUBPLANA M. and H.

For description and synonymy see Rep. U. S. G. S. Terr., Vol. IX., p. 99.

Of this species I have but one specimen, retaining the shell with surface markings, in part. As presumed by Meek, who had seen only internal molds, the ornamentation consists of fine concentric striæ. The shell itself is quite thin. The dentition and muscular impressions are not shown, but in other respects the shell agrees closely with the original description.

Locality and Position.— Near wagon road just south of basalt-capped mesa, two miles southwest of Santa Rosa Mountain, in shales of Fort Pierre age. (Col. Univ. Coll. Pal., No. 14978.)

Crassatellidæ.

Genus ASTARTE Sowerby.

ASTARTE EVANSI (H. and M.) Whitfield. (Pl. V., Fig. 24, *a*, *b*, *c*.)

For description and synonymy see Rep. Geol. Black Hills of Dakota, p. 413.

This species is quite abundant in the Cerrillos region, especially in the Fort Pierre shales southwest of Santa Rosa Mountain. The shells agree closely with the description given by Whitfield. The strong muscular imprints and crenulate margins of the valves are well shown. The surface ornamentation is rather variable, the concentric lines being quite simple in cases, gathered into irregular wrinkles in others, or even developing into fairly regular low concentric undulations separated by narrower interspaces. Some internal molds show traces of the obscure radiating lines mentioned by Meek.

Associated with the typical forms of *A. evansi* found in the inclusion of shales in the lava west of the reservoir, were a number of internal molds of smaller forms which are referred to the young of this species. A wax impression of the hinge of a moderately large example shows the characteristic dentition of *Astarte.*

Locality and Position.—Near wagon road, just south of basalt-capped mesa, two miles southwest of Santa Rosa Mountain, in shales of Fort Pierre age. Also from inclusion of shales in lava in branch of San Marcos Arroyo, half a mile west of reservoir. An impression from the sandstones along wagon road three miles northwest of Waldo is referred to this species with some doubt. One specimen from the top of the Galisteo Monocline, south of wagon road, may belong to this species. (Col. Univ. Coll. Pal., No. 14979.)

Cardiidæ.

Genus PROTOCARDIA Beyrich.

? PROTOCARDIA RARA E. and S.

For description and synonymy see Rep. U. S. G. S. Terr., Vol. IX., p. 176.

A few poorly preserved specimens are doubtfully referred to this species. They differ from the typical *P. rara* in having the radiating costæ continuing farther toward the beak. The umbonal region is quite gibbous, however, and in other respects they would seem to agree fairly well with the description given by Evans and Shumard. The specimens are too fragmentary to speak with certainty.

Locality and Position. — Achavica Arroyo, one mile northwest of Grand Central Mountain in sandstone of Fort Pierre age. Also from near wagon road just south of basalt-capped mesa, two miles southwest of Santa Rosa Mountain, in shales of same age. (Col. Univ. Coll. Pal., No. 14980.)

Veneridæ.

Genus CYPRIMERIA Conrad.

CYPRIMERIA? SULCATA sp. nov. (Pl. VI., Fig. 25, *a*, *b*, *c*, *d*.)

Shell moderately thick, of medium size, somewhat convex, subcircular in outline; beaks small, situated a little anterior to the middle; cardinal margin sloping with nearly equal convexity in both directions from beaks; anterior end regularly rounded; posterior end subtruncate; ventral margin regularly curved; hinge not well preserved, but shows what appears to be the dentition of *Cyprimeria;* muscular scars ovate, not often shown; pallial sinus (only seen in one specimen) shallow. Surface ornamented with fine concentric lines.

On internal molds the posterior portion of each valve is marked by a broad, shallow sulcus, which originates on the upper portion of the shell posterior to the beaks, curves downward toward the ventral margin, is roughly parallel to the posterior margin, and becomes more distinct as it progresses.

Length of average specimen 50 mm.; height 43 mm.; convexity (both valves) 10 mm.

This species is very abundant, but since the matrix is usually a dense hard sandstone considerably metamorphosed, or profoundly metamorphosed shales, no perfect specimens were secured. The rather prominent sulcus seems to the writer to be a character of generic value, but he does not feel justified in establishing a genus on the basis of such fragmentary material. The figure of *C. discus* Math. which appears in Zittel's "Grundzüge der Palaeontologie," p. 298 (Eastman's Zittel, p. 415) shows what appears to be a depression of the nature found in the specimens at hand. I have not been able to secure the description of this species, so cannot make the desired comparison.

Locality and Position.—Achavica Arroyo, one mile northwest of Grand Central Mountain, in sandstones and shales of Fort Pierre age. Two specimens from further south in the Arroyo, one mile due west of the mountains, in shales of same (?) age, are doubtfully referred to this species. Near the wagon road just south of basalt-capped mesa, two miles southwest of Santa Rosa Mountain, a number of specimens with portions of the shell still adhering were secured from shales of same age. A few specimens from the inclusion of shales in lava half a mile west of the Reservoir in San Marcos Arroyo are of doubtful identity. (Col. Univ. Coll. Pal., No. 14981.)

Solenidæ.

Genus SOLEN Linn.

? SOLEN CUNEATUS Gabb. (Pl. I., Fig. 4.)

Solen (*Hypogella*) *cuneatus* Gabb, 1869, Geol. Surv. Cal. Palæont, Vol. II., p. 175, pl. 29, fig. 61.

To this species I refer, with some uncertainty, a poorly preserved right valve. The shell was evidently narrowed anteriorly, as shown by the lines of growth, which gradually approach the straight hinge margin as they pass forward. The posterior end is broadly convex, and the shell agrees closely in size with Gabb's species.

Locality and Position.—Near wagon road just south of basalt-capped mesa, two miles southwest of Santa Rosa Mountain, in shales of Fort Pierre age. (Col. Univ. Coll. Pal., No. 14982.)

Myidæ.

Genus CORBULA Bruguière.

CORBULA NEMATOPHORA var. FITCHI var. nov. (Pl. I., Fig. 3.)

Cf. *Corbula nematophora* Meek, Eleventh Annual Rep. U. S. Geol. and Geog. Sur. Terr., p. 290, pl. 3.

Shell small, subtriangular, convex; beaks fairly prominent, a little anterior to the middle; cardinal margin sloping almost equally from beaks in both directions; anterior end regularly rounded; posterior end truncated above, rounding rather sharply into ventral margin below; ventral margin nearly straight posteriorly, rounding regularly into anterior margin, subangular umbonal ridge extending from beaks to postero-ventral margin. Surface ornamented with distinct concentric ridges, quite promiment, and separated by wider interspaces.

Length of average specimen, 14 mm.; height, 11 mm.; convexity of single valve, 3–4 mm.

This form is fairly abundant, and seems to preserves its features without great variation. I cannot doubt its close relation to *C. nematophora*, but it seems to me that our specimens are distinct from either of the two widely different forms figured by White. The distinctly subtruncate posterior end and straight posterior portion of ventral margin will serve to distinguish our form. It may be distinguished from *C. filosa* Stanton by the above features and the prominent concentric ridges. The variety is named after Mr. Hereford G. Fitch, who accompanied the writer during some of his earlier work in this region.

Locality and Position.— Achavica Arroyo, one mile northwest of Grand Central Mountain, in sandstone of Fort Pierre age. (Col. Univ. Coll. Pal, No. 14983.)

GASTROPODA.

Patellidæ.

Genus ACMÆA Eschscholtz.

ACMÆA CERRILLOSENSIS sp. nov. (Pl. I., Fig. 9, *a*, *b*.)

Shell exceedingly small for this genus, very thin, depressed, conical, apical angle large; apex but slightly eccentric, rather obtusely pointed; in some specimens showing a slight tendency toward forward obliquity; aperture circular. Surface ornamented by exceedingly fine concentric striæ, while near the outer edge of some specimens there seems to be a slight tendency toward the development of minute concentric ridges. Uncertain evidence of radiating striæ occasionally seen.

Diameter of average specimen, 1.5 mm. Diameter of largest specimen seen, 2.5 mm.

This tiny shell is exceedingly abundant in the black calcareous shales just north of the town of Cerrillos, and may be readily distinguished from other species of *Acmæa* by its minute size. The extreme abundance of the shell without the presence of larger individuals, together with the indications of mature growth furnished by the development of the slight concentric ridges, will not admit of its being considered the young of some larger species. On none of the specimens could a muscular scar be made out. The species is referred to *Acmæa* mainly on the basis of its external characters.

Locality and Position.— North of the town of Cerrillos, in shales of Fort Benton age. (Col. Univ. Coll. Pal., No. 14984.)

Genus SCURRIA Gray.

SCURRIA? CONIFORMIS sp. nov. (Pl. I., Fig. 8, *a*, *b*.)

Shell small, high conical, beak nearly central, apparently directed a little forward; aperture nearly or quite circular. Sides of shell slightly concave, the apical angle being about 65 degrees. Surface ornamented by fine concentric striæ.

Diameter of type specimen, 6 mm.; height, about 3.5 mm.

I have but three specimens of this shell, the immediate apex in each case being broken off. Enough remains, however, to indicate a more or less distinct inclination of the apex to one side. Regarding the generic relationships of this species I am in considerable doubt. Not having the original description of the genus *Scurria* at hand, I have had to rely on brief quoted descriptions, and those I have seen all describe the aperture as oval, or rounded oval. As noted above, in the species described the aperture is nearly or quite rounded. At the same time the very high conical shape and small apical angle distinguish it from other patelliform shells.

Locality and Position.— North of the town of Cerrillos, in shales of Fort Benton age. (Col. Univ. Coll. Pal., No. 14985.)

Naticidæ.

Genus NATICA Lamarck.

NATICA sp. undet.

Of this genus I have but one specimen, from the Fort Pierre shales southwest of Santa Rosa Mountain. Although it does not seem to agree with any described form, it is too poorly preserved to admit of specific identification or description. (Col. Univ. Coll. Pal., No. 14986.)

Turritellidæ.

Genus TURRITELLA Lamarck.

TURRITELLA GALISTEOENSIS sp. nov. (Pl. I., Fig. 5.)

Shell rather small, elongate, slender, sides straight; volutions apparently not more then nine or ten when full grown; sides of volutions slightly convex; suture deeply impressed. Surface marked by four to five fine, compressed, elevated spirals, separated by wide interspaces; the upper two spirals on each whorl usually smaller and situated closer together.

All of the specimens at hand are more or less broken, but the largest were apparently not more than 25–30 mm. in length; diameter of last whorl about 7–8 mm.

This species seems most closely allied to the Colorado variety of Stanton's *Turritella whitei*, and it is possible that those specimens should be included as a variety of our species. It seems to the writer, however, that the smaller size of our species, and the total absence of the finer intermediate revolving striæ, so far as seen, make them specifically distinct. Certainly our species must be regarded as undoubtedly distinct from the typical *T. whitei*, as shown by the Utah forms, while the forms from Colorado seem to me to be more closely related to our species than to those from Utah.

Locality and Position. — Various places in the Galisteo Valley; most abundant in concretions in shales of Fort Pierre age, near wagon road just south of basalt-capped mesa, two miles southwest of Santa Rosa Mountain; also in the Fort Pierre (?) shales in Achavica Arroyo, one mile west of Grand Central Mountain. (Col. Univ. Coll. Pal., No. 14987.)

Strombidæ.

Genus ROSTELLARIA Lamarck.

ROSTELLARIA? TEXANA Conrad.

Rostellaria? texana Conrad 1857, Rep .U. S. and Mex. Bound. Surv., Vol. I., pt. 2, p. 158, pl. 13, figs. 4, *a*, *b*.

There is in the collection an internal mold which agrees closely with the one which Conrad referred to *Rostellaria?*, giving the specific name *texana*. The form of the volutions, the character of the depression near the suture, and the general outline of the specimen are identical with Conrad's type.

Locality and Position. — Achavica Arroyo, one mile northwest of Grand Central Mountain, in sandstones of Fort Pierre age. (Col. Univ. Coll. Pal., No. 14988.)

Tritoniidæ.

Genus TRITONIUM Link.

TRITONIUM KANABENSE Stanton. (Pl. I., Fig. 6.)

Tritonium kanabense Stanton, 1893, Bull. U. S. G. S., No. 106, p. 150, pl. 31, fig. 12.

Of this beautiful species I have a number of examples, some of which are in a very good state of preservation. Our forms are larger than Stanton's type as a rule, but agree closely in other respects with his description. The spirals are strong, elevated, and flattened, and separated by broad interspaces, in which are seen from one to three fine lines, especially on the last whorl. The specimens vary in size, from those smaller than Stanton's type to forms whose length was not less than 40 mm.; and with a greatest breadth of 16 mm.

Locality and Position.—Near wagon road just south of basalt-capped mesa, two miles southwest of Santa Rosa Mountain, in shales of Fort Pierre age. One small specimen from the inclusion of Fort Pierre shales in lava half a mile west of Reservoir in San Marcos Arroyo probably belongs to this species. (Col. Univ. Coll. Pal., No. 14989.)

Volutidæ.

Genus ROSTELLITES Conrad.

Cf. Rostellites ambigua Stanton. (Pl. I., Fig. 7.)

Rostellites ambigua Stanton, 1893, Bull. U. S. G. S., No. 106, p. 156, pl. 33, figs. 8–10.

One poorly preserved internal mold seems most closely allied to this rather variable species, although the whorls are probably more convex. The suture was evidently slightly channeled, the surface ornamented with closely set spirals and transverse costæ, the latter nearly obsolete on body whorl.

Locality and Position.—Just north of Cerrillos in shales of Fort Benton age. (Col. Univ. Coll. Pal., No. 14990.)

Rostellites dalli var. wellsi var. nov. (Pl. I., Fig. 13.)

Rostellites dalli Stanton, 1893. Bull. U. S. G. S., No. 106, p. 156, pl. 33, fig. 13. Not *Rostellites dalli* Stanton, *ibid.*, figs. 11 and 12.

Of this species I have but one specimen, collected by Mr. J. L. Wells from the shales near the eruptive core, in the northern part of the town of Cerrillos. The specimen is only fairly well preserved, the front portion of the shell and the apex being absent and the lips imperfect. Following is the description:

Shell of medium size, moderately slender, fusiform; spire elevated, less than aperture in length; volutions six or seven in number, convex, with narrow constriction below suture; body-whorl large, ventricose; shoulder angle prominent, especially on body-whorl. Surface ornamented with distinct moderately broad spirals, separated by somewhat narrower interspaces, and by prominent, rounded transverse costæ which become obsolete below the middle of the body whorl. On last revolution there are about twenty (eighteen shown and part of shell missing) spirals and ten of the transverse costæ. Aperture long and narrow, with slight notch at posterior end, as indicated by lines of growth on shoulder; portion of shell near lips broken away. Apex not preserved.

Length of specimen when complete probably about 70 to 75 mm.; greatest breadth when complete, about 30 mm.

The shell agrees closely with the stouter individual figured by Stanton. Through the courtesy of Mr. Stanton I had the opportunity to examine his types, and was convinced of the identity of our form with the stouter variety. The spirals are rather broader in our form, although not nearly so much so as Stanton's figure would lead one to suppose. At the same time it seemed to me that the more typical forms of Stanton's types were entirely distinct from the stouter individual, and while the differences may not be specific, they certainly warrant the removal of that form to a distinct variety. In this opinion Mr. Stanton concurred, and on comparing our type with his stouter form, he regarded them as identical.

The variety is named for the collector, Mr. J. L. Wells. I am of the opinion that the specimens figured in the report of Herrick and Johnson on the Geology of the Albuquerque Sheet * have been wrongly identified.

Locality and Position. — Just north of Cerrillos, in shales of Fort Benton age. (Col. Univ. Coll. Pal., No. 14991.)

Cancellariidæ.

Genus ADMETOPSIS Meek.

ADMETOPSIS? ELEVATA sp. nov. (Pl. I., Fig. 14.)

Shell small, slender, subconical; volutions slightly convex, five or six in number; spire elevated, acute; suture slightly channeled; height of body whorl equal to about one half the total height of shell. Surface ornamented by small, low, rather closely set, transverse costæ, as well as by indefinite revolving lines; lines of growth also visible.

Length of average specimen, 13 mm.; breadth 6 mm.

Although this species is very abundant, it was not possible to secure a single perfect individual. The surface markings are only known from tiny fragments of shell still adhering to a few of the specimens, but it was seen that the spiral lines continue to the top of the body whorl, and are also present on the other whorls. In this respect our species differs from *A. rhomboides* Meek, to which it seems most closely related, as well as in its much more elevated spire, conical form, and less convex volutions. The presence of columellar folds is apparently indicated, but of this point I cannot be certain.

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* *Bull. Univ. New Mexico,* Vol. II., Pt. I., p. 37, Pl. III., figs. 3 and 5.

Locality and Position. — Near wagon road just south of basalt-capped mesa, two miles southwest of Santa Rosa Mountain, in shales of Fort Pierre age. (Col. Univ. Coll. Pal., No. 14992.)

CEPHALOPODA.

AMMONOIDEA.

Lytoceratidæ.

Genus HELICOCERAS d'Orbigny.

? HELICOCERAS PARIENSE White.

For description and synonymy see Bull. U. S. G. S., No. 106, p. 164.

A very small weathered fragment is doubtfully referred to this species. The surface is marked by strong, rather abruptly rounded oblique annulations, which are less prominent on the inner side of the whorl, while there is doubtful evidence of nodes on the outer side.

Locality and Position. — Near wagon road just south of basalt-capped mesa, two miles southwest of Santa Rosa Mountain, in shales of Fort Pierre age. (Col. Univ. Coll. Pal., No. 14993.)

Genus BACULITES Lamarck.

BACULITES ANCEPS Lamarck. (Pl. XI., Fig. 30, *a*, *b*, *c*.)

For description and synonymy see Rep. U. S. G. S. Terr., Vol. IX., p. 406.

There are a number of specimens of *Baculites* in the collection which are evidently identical with the Texas form referred by Dr. Roemer to *B. anceps*. In a few individuals the obscure ridges on the siphonal margin are a little more prominent than represented in Roemer's figures, but this character has been noted by Meek on forms regarded as identical with the Texas types. In some cases the shell itself is partially preserved, and the finer lines of growth beautifully shown. The septa are not sufficiently well preserved to be made out.

Locality and Position. — Near wagon road just south of basalt-capped mesa, two miles southwest of Santa Rosa Mountain, in shales of Fort Pierre age. One poorly preserved impression of this same species was found associated with *Inoceramus labiatus* and *Stantonoceras pseudocostatum* near the wagon road three miles northwest of Waldo. Fig. 30, *c*, is drawn from the cast of an impression found in the Fort Pierre sandstone one mile northwest of Grand Central Mountain, in Achavica Arroyo. The shell was evidently crushed, and is doubtfully referred to this species. (Col. Univ. Coll. Pal., No. 14993.1.)

BACULITES sp. undet.

Near the base of the Madrid section, one mile west of the town, were found a few specimens of *Baculites* whose characters are too poorly preserved to admit of identification. One badly altered individual comes from the inclusion of shales caught up in the lava half a mile west of the Reservoir in San Marcos Arroyo.

Amaltheidæ.

Genus PLACENTICERAS Meek.

PLACENTICERAS PLACENTA Dekay (sp). (Pl. VII., Fig. 26, *a*, *b*.)

For description and synonymy see Bull. U. S. G. S., No. 106, p. 169.

Associated with *Stantonoceras pseudocostatum*, in the shales northwest of Waldo, were several fragments of this species which seem closely identical with the New Jersey types. The shell was sometimes a foot or more in diameter, lenticular in form, with ventrum narrowly rounded to flat and aperture elongate sagittate. The septa are not well shown, but were apparently closely similar to those of the New Jersey forms, being less crowded than in the western types described by Meek.

Associated with *P.? intermedium* and *P.? rotundatum*, in the sandstones west of Madrid, I found one example which might belong to the smaller variety of this species which Stanton described from Colorado and Utah, or might be the young of the form described above. The septa are less crowded than in the larger western forms described by Meek. Our specimen has the flat narrow venter, smooth surface, and measures 120 mm. in greatest diameter, a portion of the shell missing.

Locality and Position.—The larger form is found in the Cretaceous beds near wagon road three miles northwest of Waldo. The smaller form came from one mile west of Madrid in strata of Fort Pierre age. (Col. Univ. Coll. Pal., No. 14994 *a, b.*)

PLACENTICERAS ? sp. undet.

In the collection from northwest of Waldo are a few fragments of a form which resembles *P. placenta* Dekay in some respects, but which has more convex sides, faint lateral nodes near the periphery, and more rounded internal whorls, while the flat keel and more or less sagittate form of aperture still persist. This probably represents a distinct species, but until better material is available its relations cannot be determined. (Col. Univ. Coll. Pal., No. 14994 *c.*)

PLACENTICERAS ? INTERMEDIUM sp. nov. (Pl. VIII., Fig. 27, *a, b.*)

Shell of medium size, sublenticular in form, sides of outer whorl progressively increasing in convexity; ventrum narrowly flattened, the flattened space bordered on each side by small, compressed, alternating nodes having their longer diameters parallel to the direction of the peripheral curve; these nodes becoming nearly obsolete on later portion of shell, where the ventrum is broader and more rounded; greatest convexity of outer whorl near umbilical angle; umbilicus small, volutions deeply embracing; umbilical angle fairly well defined, and provided with moderately strong pointed nodes; umbilical angle of inner whorls very marked, and provided with very small, faint nodes; a faint row of nodes beginning to show near ventral margin, especially on later portion of outer whorl. Surface showing obscure sigmoid lines of growth, and very faint traces of elongated prominences originating at the nodes along the umbilical and ventral margins. Septa similar to *Placenticeras placenta* Dekay, but simpler and not at all crowded.

Greatest diameter of type specimen, 110 mm.; greatest transverse diameter of body whorl, 35 mm.

The writer has in preparation a paper on the development of the *Placenticeratidæ*, in which the relation of this and the following forms will be treated in detail. At present I am only prepared to say that this species is descended from the same ancestors as the *P. placenta* of Meek, and that from the former (*P. ? intermedium*) are descended the species described next below. The present form is closely related to *P. placenta* var. *intercalare* Meek, but the two are very evidently not specifically identical. As to whether or not it should be classed under *Placenticeras* I am still uncertain. It is unquestionably intermediate in position between the immediate ancestor of the true *Placenticeras* and the genus *Stantonoceras* described below, but as to the exact value of its intermediate characters I am as yet in doubt.

Associated with this form, and directly descended from it, is the species *P.? rotundatum* described below.

Locality and Position.— One mile west of Madrid, in sandstone of Fort Pierre age. (Col. Univ. Coll. Pal., No. 14995.)

PLACENTICERAS? ROTUNDATUM sp. nov. (Pl. IX., Fig. 28, *a*, *b*.)

Ammonites guadalupæ Gabb., 1872, Proc. Acad. Nat. Sci. Phila., for 1872, p. 264, pl. 9, fig. 1, pl. 10, figs. 1, 1*a*.

Not *A. guadalupæ* Roemer, Kreide von Texas, p. 32, pl. 2, fig. 1, *a*, *b*, *c*.

Shell of medium size, thick discoidal, sides of outer whorl convex; ventrum broadly rounded except on younger portion of whorl, where it is indistinctly truncated and bears small compressed alternating nodes; greatest convexity of outer whorl midway between umbilical and ventral margins; umbilicus small, volutions deeply embracing; umbilical angle rounded and provided with very strong pointed nodes; umbilical angle of inner whorls indefinite, and provided with strong, prominent nodes, which are partially concealed by the outer enveloping whorl; nodes near ventral margin fairly well developed. Surface marked by obscure sigmoid lines of growth and indefinite elongated prominences inclined forward from the nodes along the umbilical angle; fainter prominences directed back from nodes near ventral margin. Septa not well preserved, but evidently similar to typical *Placenticeras*, although less crowded.

Greatest diameter of type 120 mm.; greatest transverse diameter of outer whorl, 40 mm.

This form is the direct descendant of *P. intermedium*, but has so far advanced as to make it, in the opinion of the writer, specifically distinct. It may be distinguished from that form by the much greater thickness of the shell as a whole, the entire loss of sagittate form of aperture, the greater prominence of the nodes near the umbilical and ventral margins, the more rounded umbilical angle, the large nodes on the umbilical angle of the inner whorls, the loss of the alternating nodes at a much earlier stage, and the more broadly rounded ventre.

That *Ammonites guadaloupæ* Roemer is descended from this form is also evident. But it seems to the writer that the former has so far advanced as to make it specifically distinct from our type. The typical *guadaloupæ* may be distinguished from *P.? rotundatum* by the much greater development of the nodes near the ventral margin of the former, the greater distance of the inner row of nodes from the umbilical suture (a result of the loss of the umbilical angle due to the distention of the shell below that angle by the increasing convexity of the next inner whorl), and by the fact that the youngest portion of the outer whorl is much more maturely developed than even a much later stage in our type.

As stated in the description of *P. ? intermedium*, the reference of this species to *Placenticeras* is not final, and cannot be until the further study of more and better material is completed.

Locality and Position. — One mile west of Madrid, in sandstones of Fort Pierre age. (Col. Univ. Coll. Pal., No. 14996.)

Genus STANTONOCERAS gen nov.

Genotype. — *Stantonoceras pseudocostatum* Johnson.

Shell large in typical species; descended from the same ancestor as *Placenticeras;* having stages of growth corresponding to ancestral types which possessed, in successive generations, keels that were very narrowly flat, channeled, and alternately nodose; but so far advanced at maturity as to bear little or no resemblance to the typical *Placenticeras;* outer whorls broadly rounded or subquadrate in cross-section; moderately embracing; definite ventral keel nearly or quite obsolete; umbilical angle nearly or quite imperceptible; surface ornamented with more or less prominent nodes, elongated nodes or pseudocostæ; septa similar to those of *Placenticeras*, but more simple and less crowded.

Although somewhat less accelerated than the type of this genus, I am of the opinion that *Ammonites guadaloupæ* Roemer should be included here. It is of course one of the transition types, and its generic reference must be more or less a matter of judgment. But it has advanced so far from the original stock, and has so many features in common with this genus, that it seems to me impossible to classify it elsewhere.

? STANTONOCERAS GUADALOUPÆ Roemer (sp.).

Ammonites guadaloupæ Roemer, 1852, Kreide v. Tex., p. 32, pl. 2, fig. 1, *a*, *b*, *c*.

Associated with the ancestral types of this species, or possibly from a somewhat higher horizon, at the base of the Madrid section, was one very poorly preserved specimen which probably belongs here. Both the outer and inner rows of nodes were very highly developed, while the inner coils were apparently much more highly developed than in the closely related form, *P. ? rotundatum*. Sigmoid lines of growth are well shown. The shell is too badly crushed to permit of accurate identification.

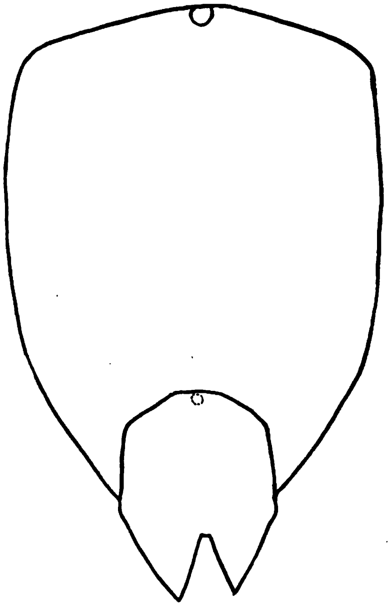
Locality and Position.—One mile west of Madrid, in sandstones of Fort Pierre age. (Col. Univ. Coll. Pal., No. 14997.)

STANTONOCERAS PSEUDOCOSTATUM sp. nov. (Pl. X., Fig. 29, *a*; Pl. XI., Fig. 29, *b*, *c*.)

Shell large, outer volutions subquadrate in cross-section, embracing about one half of the next inner coil; venter broadly rounded, indistinct outline of narrow keel remaining; umbilical angle obsolete, shell thinning out gradually to a wedge-like form toward umbilical suture. Surface ornamented by prominent, compressed elevated ridges, formed by the elongation and coalescence of the nodes nearest the umbilicus with one of the outer series, while each of the remaining nodes of this latter series appears as a shorter ridge, between each two of the longer ones. These pseudocostæ are extremely prominent on the ventro-lateral angle, being high and broad, but decrease in prominence toward the umbilicus until about two thirds of the way across the side of the whorl, when they enlarge slightly, and then become obsolete. This last enlargement marks the position of the node which in ancestral types occurs at the umbilical angle. The septa are badly worn, making the sutures appear much simpler on some parts of the shell than on others, but enough remains to show that they were similar to those of *Placenticeras*, but not crowded.

From the standpoint of its development this species, which is only known from the portions of two outer whorls and the impression of the third inner one, is most interesting. The portion of the first inner whorl is figured on Plate XI., and it will be readily seen that it corresponds closely with the outer whorl of *S.* (*Ammonites*) *guadaloupæ* Roemer, except for the slight distortion produced by the enveloping whorl. This represents the *guadaloupæ* stage in the development of *S. pseudocostatum.* The nodes are here distinct, and show only the beginnings of the elongations which reproduce the form of costæ at a later stage. Traces of the narrow keel with the alternating nodes are distinctly seen on the rounded venter.

A wax impression of the next inner whorl is figured on Plate XI. Here we see the exact reproduction of the younger portion of the outer whorl of *Placenticeras ? intermedium* Johnson, and have the *intermedium* stage in the development of *S. pseudocostatum.* The lenticular shape, narrowly truncated periphery, and alternating compressed nodes, having their longer diameters parallel to the peripheral curve, are well shown, even in so small a fragment. The accompanying figure shows the above stages as seen in cross-section. As I shall show more fully in the forthcoming paper, the intermediate stages can be carefully traced in other forms, as well as those stages preceding, in which latter case the further changes are (in reverse order) from the alternating noded keel to the channeled keel, then to the flat, and still earlier to the rounded



Cross-section of *Stantonoceras pseudocostatum* Johnson. Reduced one half.

form. The development of the pseudocostæ will also be taken up in greater detail, but it is interesting to keep in mind the fact that costæ appearing much or quite the same in form, may have entirely different origins.

Locality and Position.—Near wagon road, three miles northwest of Waldo, in strata of Cretaceous age. (Col. Univ. Coll. Pal., No. 14998.)

Genus PRIONOCYCLUS Meek.

PRIONOCYCLUS WYOMINGENSIS Meek.

For description and synonymy see Bull. U. S. G. S., No. 106, p. 171.

Of this species I have only the impression of a portion of the outer (?) and an inner whorl, but the extreme irregularity of the costæ, the elongated nodes near the umbilicus, from which nodes two costæ frequently spring, and the smaller costæ between the larger nodose ones, leave no doubt as to the identity of the form.

Locality and Position.—Just north of the town of Cerrillos, in shales of Fort Benton age. (Col. Univ. Coll. Pal., No. 14999.)

PRIONOCYCLUS MACOMBI Meek.

For description and synonymy see Bull. U. S. G. S., No. 106, p. 172.

In the shales just north of Cerrillos were found one adult individual of this species and a number of young examples. In the adult the characteristic septa are fairly well shown, and the form and ornamentation agree in detail with the description and figures referred to, leaving no doubt as to its identity. Fragments of specimens 35 to 50 mm. in diameter show the minute crenulations of the keel and the strong nodes characteristic of the species at this stage.

Locality and Position.—North of the town of Cerrillos, in shales of Fort Benton age. (Col. Univ. Coll. Pal., No. 15000.)

PRIONOCYCLUS sp. nov. (Pl. I., Fig. 15.)

Associated with *P. macombi* and *Prionotropis woolgari*, in the shales just north of the town of Cerrillos, were found a large number of young ammonoids, usually so firmly imbedded in the matrix or so profoundly altered by metamorphism that only small fragments could be secured. These small individuals, an example of which is figured on Plate I., were at first doubtfully referred to the young of *Prionocyclus macombi*, although they were seen to differ markedly from the figure of a young example of that species given on Plate XLI. of Stanton's paper. The following description of one of our forms may serve to make its relations clearer.

Shell discoidal, umbilicus quite narrow, volutions rather strongly embracing, compressed so as to be nearly flat on sides; periphery narrow, provided with a comparatively prominent, simple keel; surface of whorl ornamented with 75 to 100 (estimated from those counted on a fairly well preserved third of a volution) decidedly flexuous costæ, all of which reach the umbilical margin on the youngest part of the volution; but only every third or fourth one of which reach clear across the older portion, being rather swollen and prominent near the umbilical angle; on the periphery these costæ are bent rather abruptly and strongly forward. Diameter of type above described, 23 mm.; greatest convexity, 5 mm.; breadth of umbilicus, less than 4 mm.; breadth of outer whorl from siphonal to umbilical side, 11 mm.

A comparison with the adult of *P. macombi* will show that in these small individuals the umbilication is proportionately much greater and the costæ more flexuous — characters indicating a more accelerated stage of development than even the adult of that species. It is seen also that only every third or fourth costa reaches the umbilical margin and is there swollen and prominent — features which our specimens would seem to have in common with the adult of *macombi*. On the other hand the keel is still simple, and no nodes are developed, in which respects our specimens are noticeably less accelerated.

It might be considered that this type is the young of *P. macombi*, that species being a gerontic form in which the young would show more accelerated features. It does not seem to me, however, that the characters of the adult *P. macombi* warrant this assumption. Nor do I believe these forms can be considered the young of any known *Prionocyclus*. It is more probable that they represent the young of a species not yet known, which is closely related to *P. macombi*, but more accelerated in its development. The fact that a number of the young were found, but no adult, is not strange when it is considered that these fossils occur in metamorphosed shales close to the eruptive core, where everything is so crushed and altered that only smaller forms, or mere fragments of larger ones, are usually secured.

Locality and Position.—Just north of the town of Cerrillos, in shales of Fort Benton age. (Coll. Univ. Coll. Pal., No. 15001.)

Genus PRIONOTROPIS Meek.

PRIONOTROPIS WOOLGARI Mantell (sp.). (Pl. XII., Fig. 31, *a, b, c.*)

For description and synonymy see Bull. U. S. G. S., No. 106, p. 174.

Of this species I have two examples, one a well-preserved fragment of an adult specimen collected by Mr. J. L. Wells while excavating for the dust flues of the Cerrillos Smelter just north of the town. It was one of several fossils found in the loose shales near the eruptive core at this point, while the portion of a gerontic individual of the same species was collected at the same point by the writer. The former is by far the more interesting. The fragment (125 mm. in greatest length) is apparently a portion of the outer whorl of an individual some 160 or 180 mm. in diameter, the thickness at the smaller end of the fragment (from keel to keel) being 35 mm., at the larger end 50 mm., and the lateral thickness (through center of whorl, not including costæ) being 30 mm. at the smaller end, and 38 mm. at the larger. Nine costæ are shown, two of these being but partially developed. The keel is prominent and somewhat crenate, the nodes nearest it being compressed, their forward portions rising a little more prominently and terminating a little more abruptly than behind. The long axes of these nodes are approximately parallel to the keel, and are so strongly developed as to give the periphery, when seen in profile, the appearance of being deeply sulcated on either side of the latter. The costæ are rather pronounced, terminating at either end in prominent pointed nodes, those of the outer of the two series having the outermost compressed nodes of the third series near by. The two undeveloped costæ (separated by three of normal growth) become obsolete before reaching the line of the inner series of nodes, have the outer pointed nodes but slightly developed, with fairly prominent representatives in the flat compressed series. Faint indications of other secondary costæ may be noticed near the posterior ends of the flattened nodes of the more prominent costæ. The umbilical margin is deeply indented by the prominent nodes of the flattened series nearest the keel of the succeeding volution within. A portion of the siphuncle of this latter volution still adheres to the specimen in hand. Unfortunately not the slightest trace of the septa appears on this fragment.

A comparison of this individual with the figures given by Meek and others, shows that the nodes at the inner ends of the costæ of this specimen are very much more prominent and pointed than represented by them, being as strongly developed and as well preserved as those of the next outer series. As the accentuated development of the nodes may be safely looked upon as a progressive feature, we might infer that the individual under discussion represents a slightly more advanced stage of the evolution of this species. Another evidence of the advanced stage in the development of the species represented by this individual is found in its rather large size accompanied, however, by no gerontic characteristics. The larger specimens described by Meek, about the same size as the specimen under consideration, present unmistakeable old age characters. The outer compressed nodes have disappeared, the keel is only represented by distinctly separated, low, elongated nodes, the costæ are more distant and become pinched up at their inner extremities, not quite reaching the umbilical margin. In our specimen, however, the outer, compressed nodes are very prominent, the keel is continuous and well preserved, while the costæ are perfectly normal, and reach the umbilical margin, near which the inner nodes are strongly developed. All the evidence suggests a well preserved, normal adult individual, of a somewhat more advanced type than those represented by the figures referred to. The impression left on the umbilical margin by the next succeeding whorl within shows that this latter whorl represented, so far as can be told, essentially the same characteristics as the outer one; in other words, none of the characters of youth (such as the convex appearance of the ventrum due to comparatively prominent keel with adjacent compressed nodes which are but slightly developed) had persisted so late in the history of the individual. It is to be regretted that the validity of the evidences mentioned could not be tested by a comparison of the sutures.

If the specimen 160 to 180 millimeters in diameter represents a normal adult specimen in this more advanced stage of the development, we should expect gerontic individuals to be correspondingly larger. It was not surprising, then, to find at this same locality, and practically at the same horizon, a portion of an individual which must have measured from 250 to 300 mm. in its greatest diameter, presenting all the characters of gerontism. The outer compressed nodes have apparently disappeared, the costæ are elevated and compressed, the inner nodes are almost entirely absent, while the next outer series is only represented by low rounded projections at the outer ends of the costæ. The costæ, however, continued to quite near the umbilical margin, which might be expected in a more advanced type where the inner nodes are so very highly developed in earlier life. The sutures are too poorly shown to be made out.

Locality and Position.—Just north of the town of Cerrillos, in shales of Fort Benton age. (Col. Univ. Coll. Pal., No. 15002.)

Stephanoceratidæ.

Genus SCAPHITES Parkinson.

SCAPHITES WARRENI M. and H.

For description and synonymy see Bull. U. S. G. S., No. 106, p. 185.

Of this species I have two impressions, only one of which is well preserved. The closely involute inner volutions and a part of the deflected body-portion are represented. As only a small part of the latter is shown, the greater prominence of every fourth or fifth costa, and the bifurcation of the same, which are characteristic of this portion of the shell, cannot be noted. Nevertheless the general features are such as to leave little doubt as to its identity. The shell must have been about 33 mm. in length, and 29 mm. in height.

Locality and Position.—Just north of the town of Cerrillos, in shales of Fort Benton age. (Col. Univ. Coll. Pal., No. 15003.)

VERTEBRATA.

PISCES.

TELEOSTEI.

Berycidæ.

Genus BERYX Cuvier.

BERYX sp. undet. (Pl. I., Fig. 12, *a.*)

Numerous fish scales in the shales north of Cerrillos are referred to *Beryx* on the basis of the characteristic markings they exhibit. Associated with them are scales of the form shown in Fig. 12, *b*, of whose identity I am in doubt.

Locality and Position. — Just north of the town of Cerrillos in shales of Fort Benton age. Also in shales of Fort Pierre age near wagon road just south of basalt-capped mesa, two miles southwest of Santa Rosa Mountain. (Col. Univ. Coll. Pal., Nos. 15004 and 15005.)

PLANTÆ.*

DICOTYLEDONS.

APETALÆ.

Urticaceæ.

Genus FICUS Linn.

FICUS RHAMNOIDES Knowlton. (Pl. XIV., Fig. 33.)

Ficus rhamnoides Knowlton, 1900, Flora of the Montana Formation, Bull. U. S. G. S., No. 163, p. 47, pl. 10, figs. 1–3; pl. 11, fig. 1.

To this species are referred one fairly well preserved leaf, and a few more fragmentary specimens whose identity is not so certain. The better preserved example shows the typical form, about equally narrowed base and apex, entire margin, rather thick, straight midrib, twelve pairs of secondaries, alternate, and at an angle of about 45 degrees with midrib. Nervilles not shown.

Length of leaf, 155 mm.; breadth, 60 mm.

Locality and Position. — Half mile east of Madrid, in sandstone of Fox Hills age, thirty feet above coal. (Col. Univ. Coll. Pal., No. 15006.)

FICUS UNCATA Lesqx. (Pl. XIII., Fig. 32.)

For description and synonymy see U. S. G. S. Terr., Vol. VII., p. 197.

Of this species I have one fragmentary leaf which shows the essential characters quite well. The leaf is large and broadly ovate; margin entire; immediate apex constricted upward into small acumen; midrib apparently channeled; secondary nerves close, parallel, camptodrome; nervilles but slightly oblique to secondaries.

In some aspects this specimen seems allied to *F. irregularis* Lesq. The midrib is hardly as thick as in the type of *F. uncata*, while the slight constriction of the immediate apex suggests *irregularis*, although the acumen is not nearly so pronounced as in that species. In other respects the identity with the type of *uncata* seems complete.

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* For the identification of the following species I am indebted to Mr. Frank Hall Knowlton.

Locality and Position.—Half mile east of Madrid, in sandstone of Fox Hills age, thirty feet above coal. (Col. Univ. Coll. Pal., No 15007.)

Cupuliferæ.

Genus QUERCUS Linn.

? Quercus sp.

In the red sandstones above the coal measures were found numerous fossil tree trunks, many of which were from one to two feet in diameter. They were usually weathered out and washed down in the arroyos, but some were seen lying horizontally imbedded in the sandstone. Thin sections from one of these fossil trees were examined by Mr. Knowlton, and I quote the following from his letter:

"The wood is a dicotyledon, and while it has been somewhat distorted by fossilization, it appears to be a species of *Quercus.* In any event it shows a highly organized dicotyledonous tree, wholly unlike anything known from the Jura-Trias, and might well belong to the Upper Cretaceous or later."

Locality and Position.—Two miles east of Cerrillos, in sandstones of Upper Cretaceous (?) age. (Col. Univ. Coll. Pal., No. 15008.)

POLYPETALÆ.

Araliaceæ.

Genus ARALIA Linn.

Aralia? sp. (Pl. XIV., Fig. 34.)

Several fragments of leaves, one of which is figured, are referred to this genus with some doubt. These are found associated with the forms above described, in the Fox Hills sandstone above the coal, half a mile east of Madrid. (Col. Univ. Coll. Pal., No. 15009.)

PLATES.

PLATE I.

PAGE.

Aucella strongi sp. nov. 121

Fig. 1, *a*, *b*, *c*, *d*. Left valves, two thirds natural size.

Fig. 1, *e*. Small right valve, two thirds natural size.

Arca madridensis sp. nov. 122

Fig. 2. Type specimen, twice natural size.

Corbula nematophora var. *fitchi* var. nov. 126

Fig. 3. Right valve of typical specimen, slightly reduced.

?*Solen cuneatus* Gabb 125

Fig. 4. Portion of right valve referred doubtfully to this species.

Turritella galisteoensis sp. nov. 128

Fig. 5. View of average specimen (type), slightly reduced.

Tritonium kanabense Stanton 129

Fig. 6. Average sized specimen, slightly reduced.

Cf. *Rostellites ambigua* Stanton 130

Fig. 7. Internal mold apparently closely allied to this species, slightly reduced.

Scurria? coniformis sp. nov. 127

Fig. 8, *a*, *b*. Two views of type specimen, slightly reduced.

Acmæa cerrillosensis sp. nov. 127

Fig. 9, *a*, *b*. Two views of average specimen, three times natural size.

Ostrea anomioides var. *nanus* var. nov. 113

Fig. 10, *a*. Interior of large lower valve.

Fig. 10, *b*. Large upper valve.

Fig. 10, *c*. Exterior of average sized lower valve.

Fig. 10, *d*. Lower valve of a form probably belonging to this species.
All slightly reduced.

Lingula subspatulata H. and M. 113

Fig. 11, *a*. Specimen from Cerrillos district.

Fig. 11, *b*. Specimen from east of Ortiz Mountains.
Slightly reduced.

Beryx sp. undet. 143

Fig. 12, *a*. Typical scale of one of this genus.

Fig. 12, *b*. Example of scale found associated with above, but of unknown identity.

Rostellites dalli var. *wellsi*. var nov. 130

Fig. 13. View of type specimen, slightly reduced.

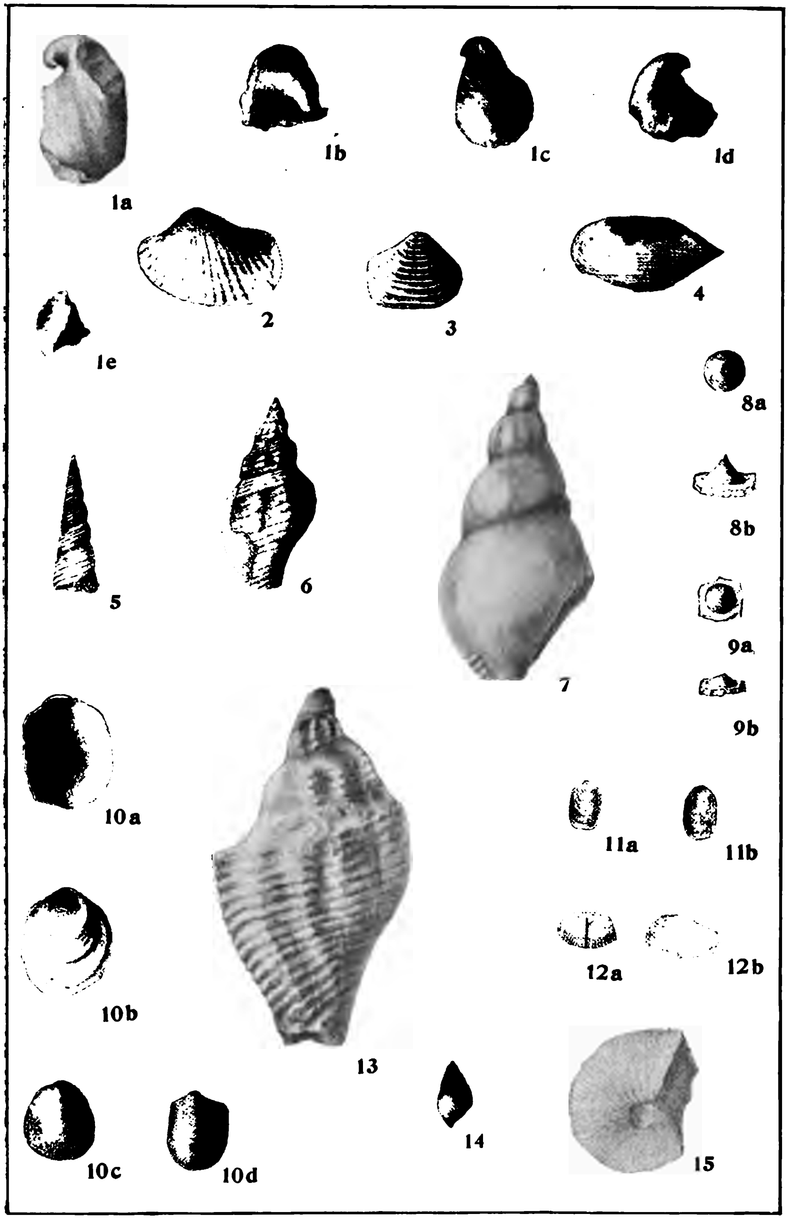
Admetopsis ? elevata sp. nov. 131

Fig. 14. View of best preserved type specimen, slightly reduced.

Prionocyclus sp. nov. 139

Fig. 15. Best preserved example, with portions of keel broken away. Slightly reduced.

Plate I.



R. B. J. and D. W. J., Del.

Plate II.

Page.

Inoceramus balchii M. and H. 117

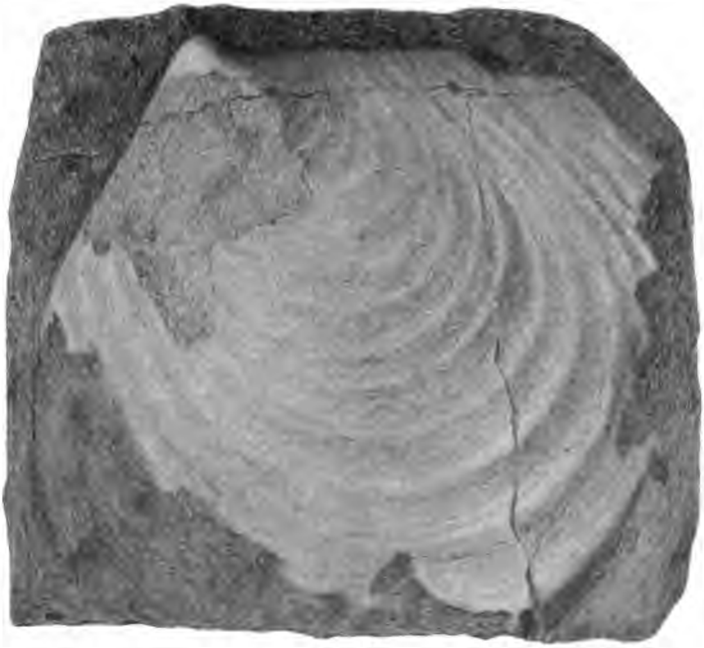
Fig. 16. Left valve, showing comparatively strong concentric undulations. Four fifths natural size.

Inoceramus fragilis H. and M. 115

Fig. 17. Internal mold of right valve. Four fifths natural size.

Inoceramus dimidius White 116

Fig. 18. Left valve, twice natural size.



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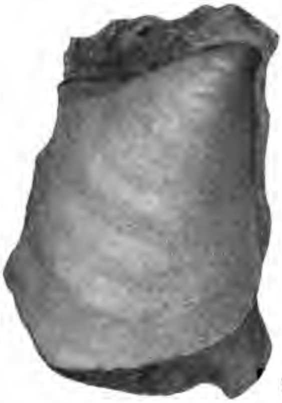

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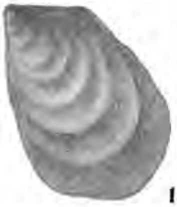


18

R. B. Johnson, Del.

PLATE III.

PAGE

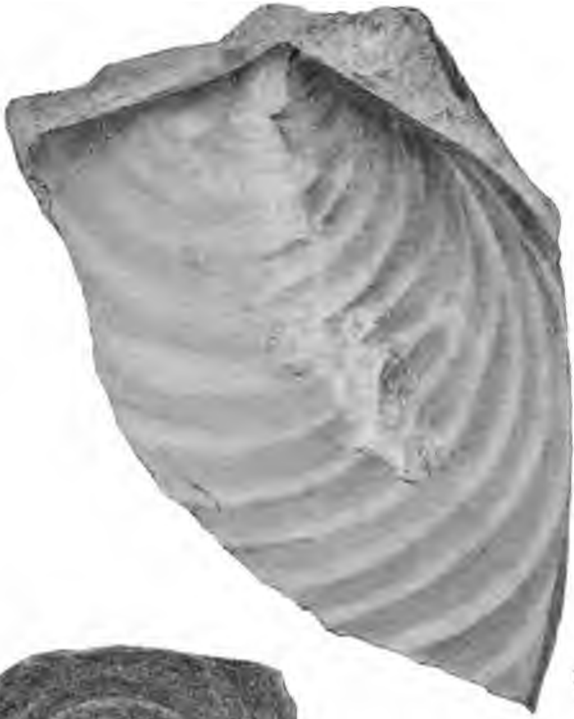
Inoceramus vanuxemi M. and H. 117

Fig. 19. Right valve, four fifths natural size.

Inoceramus sp. nov.? 118

Fig. 20, *a*, *b*. Two views of badly worn specimen, four fifths natural size.

Plate III.



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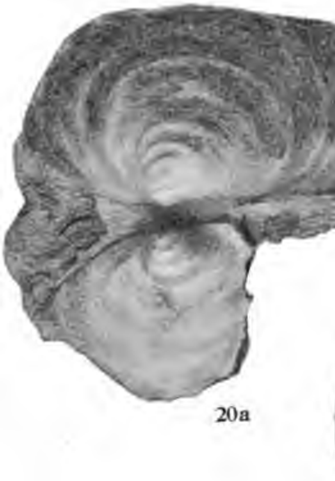

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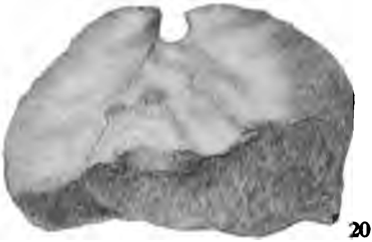

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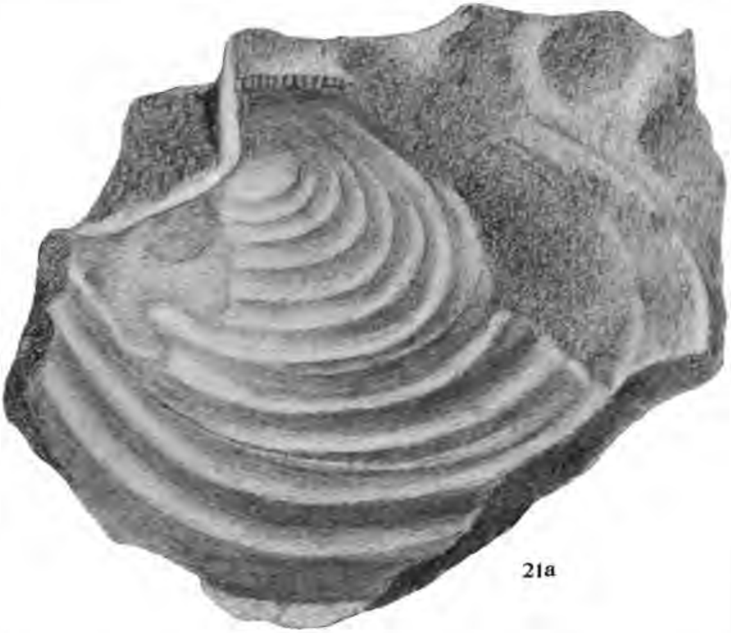
PLATE IV.

PAGE.

Inoceramus irregularis sp. nov. 118

Fig. 21, *a*, *b*. Two views of type specimen, four fifths natural size.

Plate IV.



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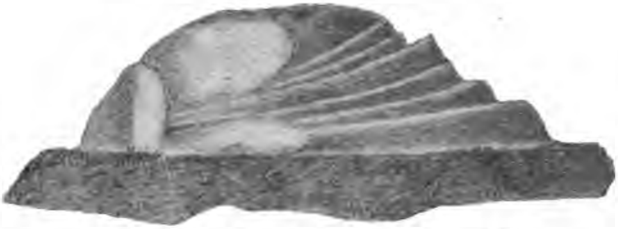

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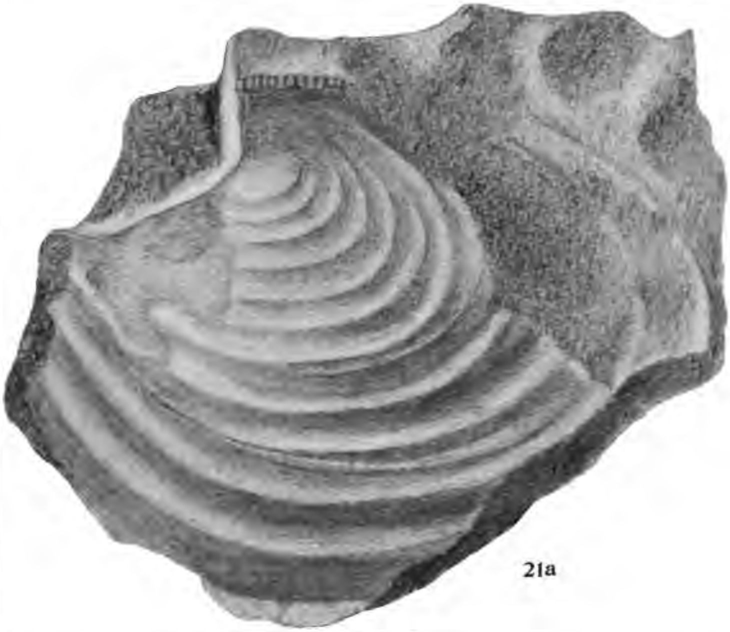
PLATE IV.

PAGE.

Inoceramus irregularis sp. nov. 118

Fig. 21, *a*, *b*. Two views of type specimen, four fifths natural size.



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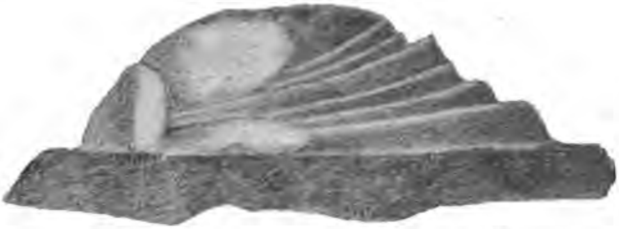

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PLATE V.

PAGE.

Inoceramus cripsii var. *barabini* Morton 118

Fig. 22. Portion of right valve, slightly reduced.

Enaocostea brooksi sp. nov. 120

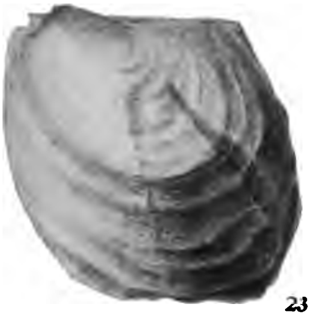
Fig. 23, *a*, *b*. Two views of type specimen, four fifths natural size.

Astarte evansi H. and M. 123

Fig. 24, *a*. Internal mold.

Fig. 24, *b*. Portion of shell, showing character of ornamentation.

Fig. 24, *c*. Internal mold of young example.



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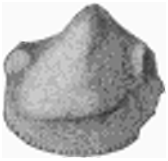

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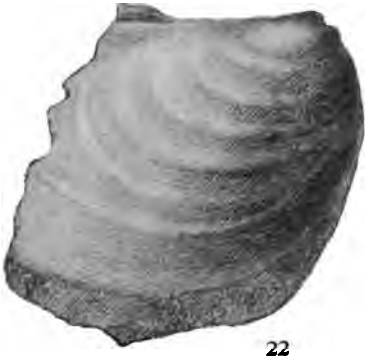

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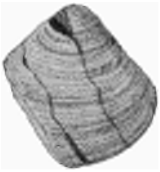

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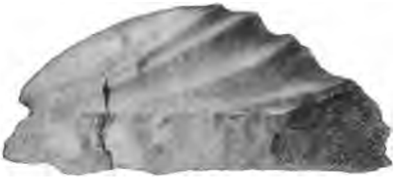

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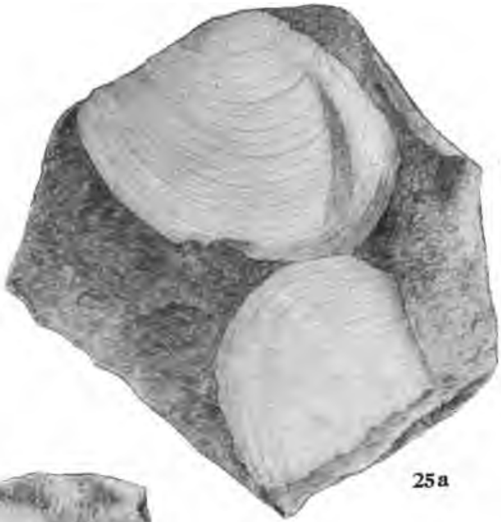
PLATE VI.

	PAGE
Cyprimeria ? sulcata sp. nov.	124

Fig. 25, *a*, *b*. Two internal molds showing sulcus, with surface markings impressed.

Fig. 25, *c*. Small right valve.

Fig. 25, *d*. Portion of average sized valve showing beak.
All slightly reduced.



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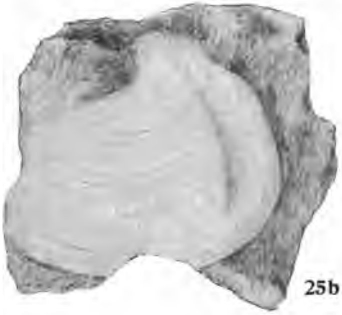

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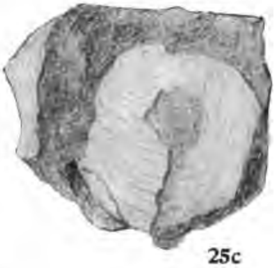

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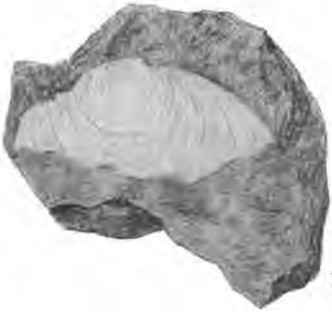

25d

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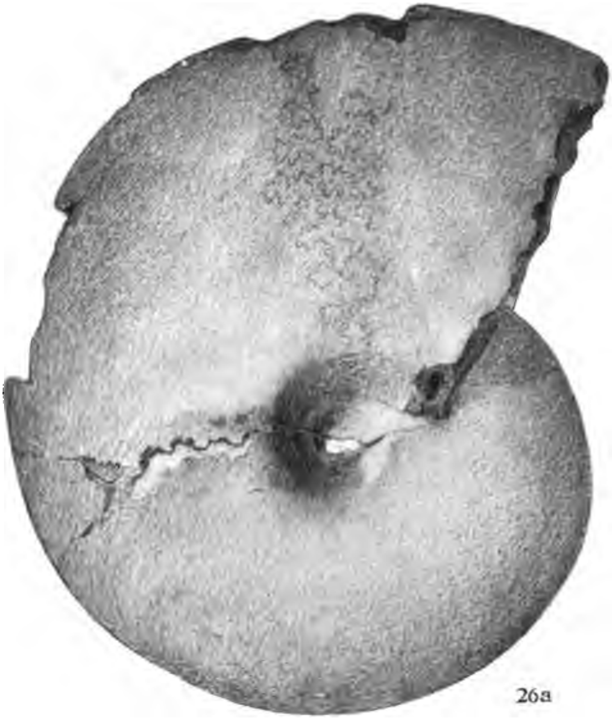
PLATE VII.

	PAGE.
Placenticeras placenta Dekay	133

Fig. 26, *a*, *b*. Two views of small specimen, four fifths natural size.



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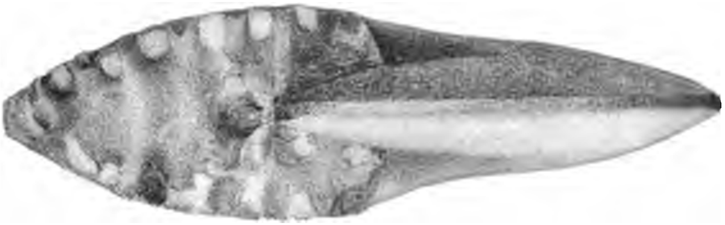

26b

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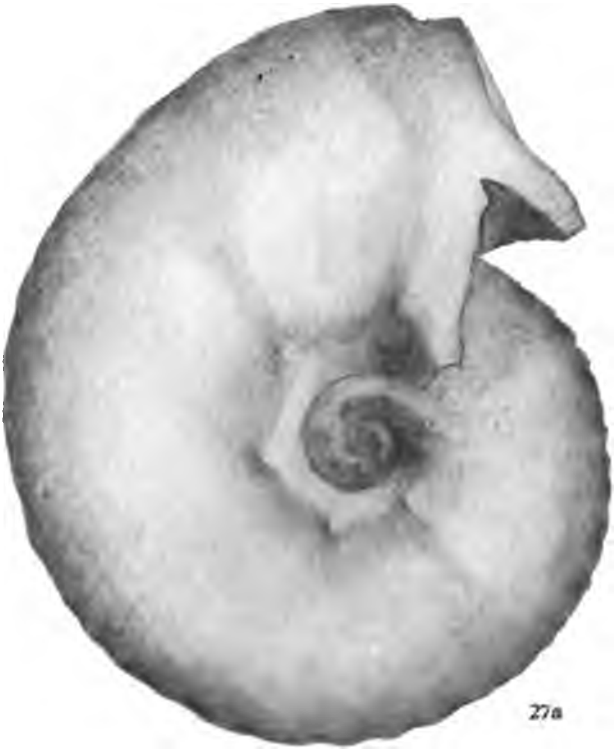
PLATE VIII.

PAGE.

Placenticeras ? intermedium sp. nov. 134

Fig. 27, *a*, *b*. Two views of type specimen, four fifths natural size.



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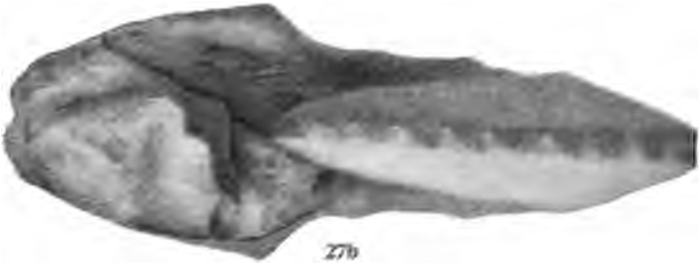

27b

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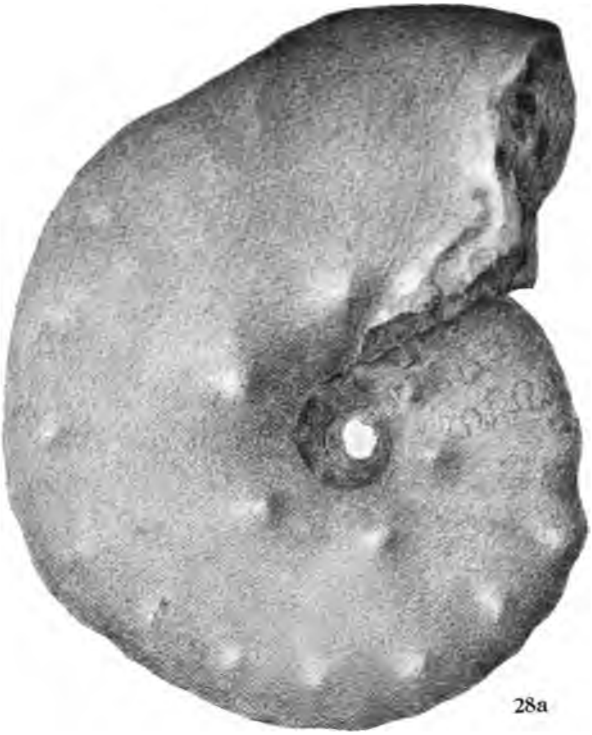
PLATE IX.

PAGE.

Placenticeras ? rotundatum sp. nov. 135

Fig. 28, *a*, *b*. Two views of type specimen, four fifths natural size.



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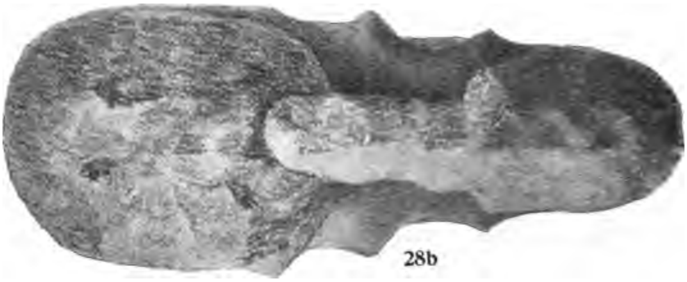


28b

R. B. Johnson, Del.

PLATE X.

PAGE.

Stantonoceras pseudocostatum sp. nov. 137

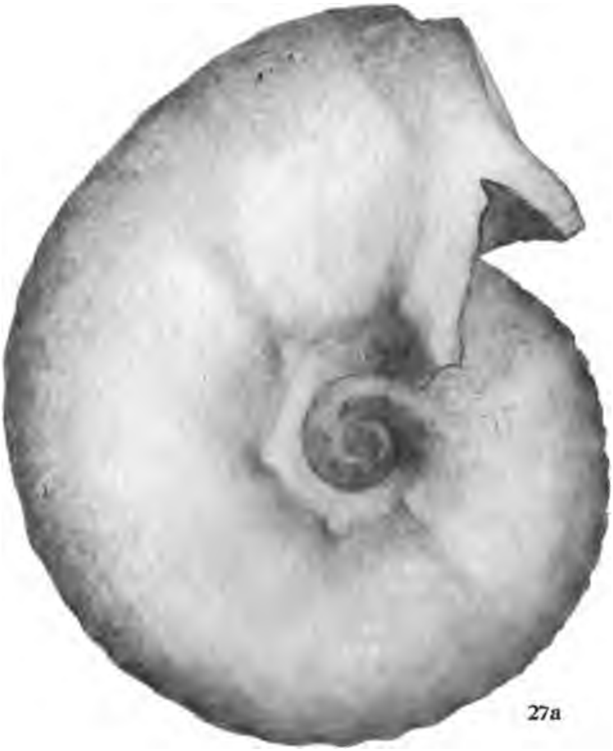
Fig. 29, *a*. Portion of outer whorl of type specimen, four fifths natural size. (See Plate XI.)

R. B. Joh

PLATE VIII.

	PAGE.
Placenticeras ? intermedium sp. nov.	134

Fig. 27, *a*, *b*. Two views of type specimen, four fifths natural size.



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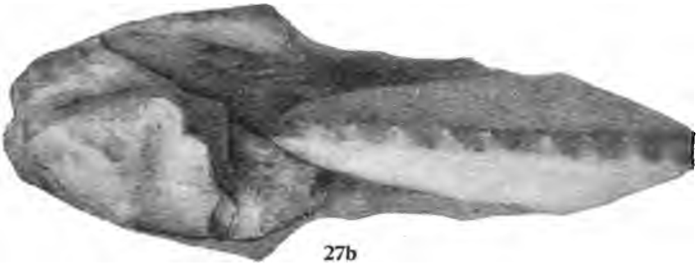

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R. B. J. and D. W. J., Del.

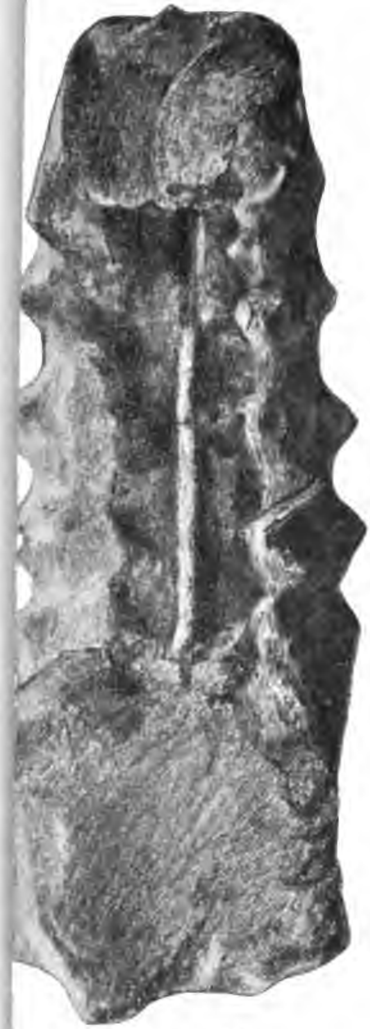
PLATE XII.

	PAGE.
Prionotropis woolgari Mantell	141

Fig. 31, *a*. Ventral view; nodes near umbilical angle showing most prominent in profile.

Fig. 31, *b*. Lateral view.

Fig. 31, *c*. Umbilical view, showing portion of siphuncle still adhering, and the prominent nodes near umbilical angle. Outer series of lateral nodes not visible.



31c

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PLATE XIII.

	PAGE.
Ficus uncata Lesqx.	144

Fig. 32. Portion of a large leaf of this species, four-fifths natural size.

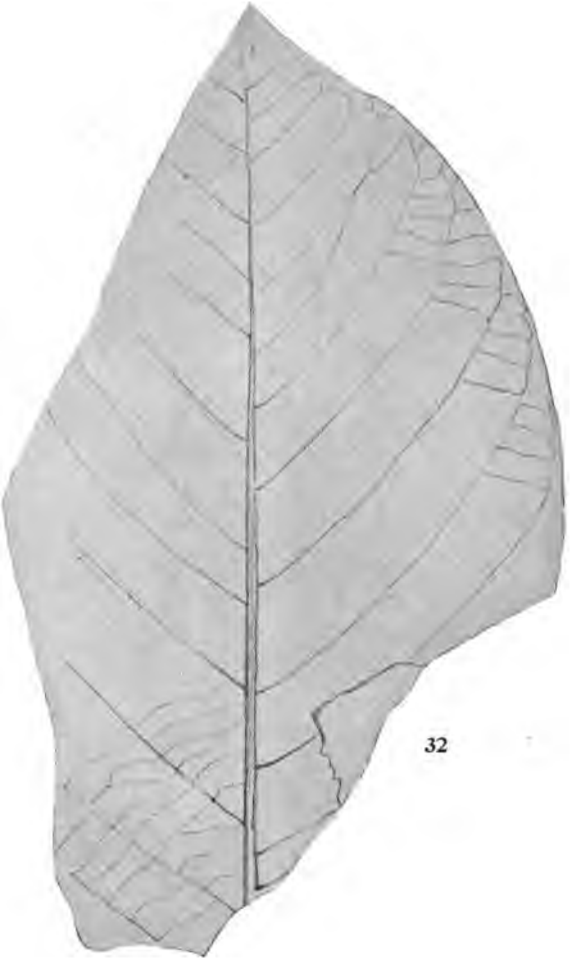

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PLATE XIV.

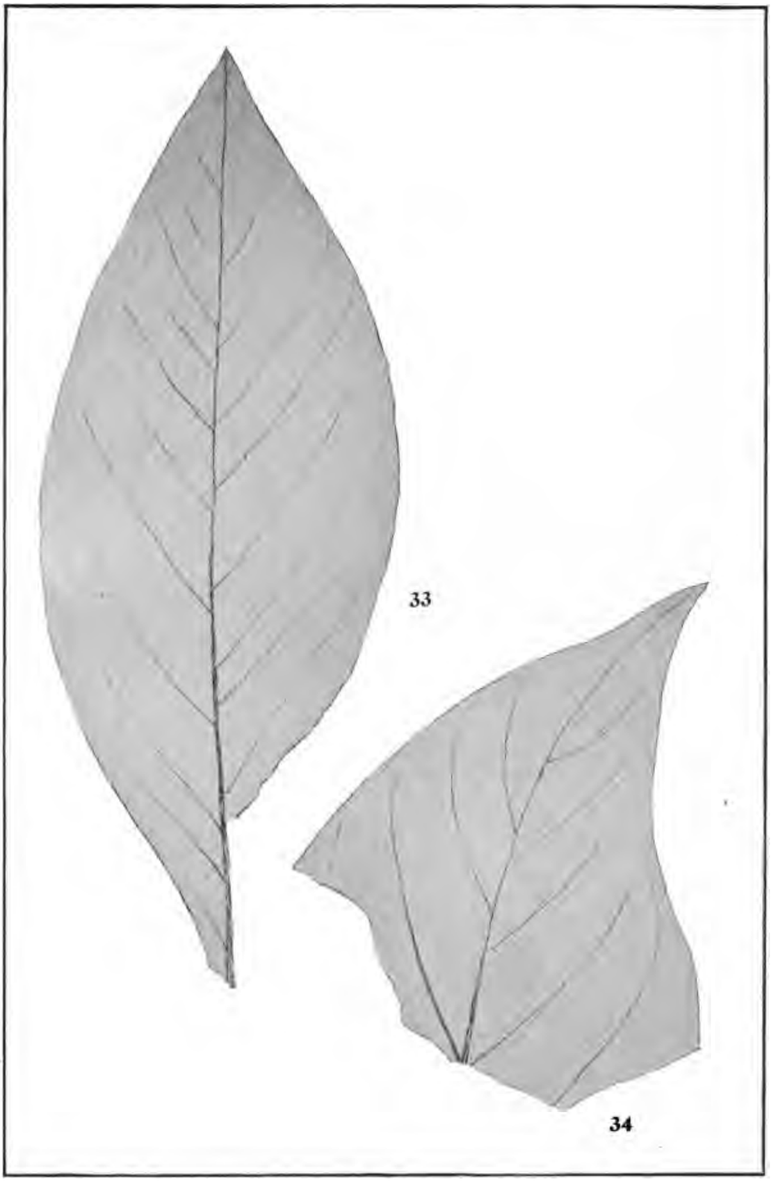
PAGE.

Ficus rhamnoides Knowlton 144

Fig. 33. Best preserved specimen, four-fifths natural size.

Aralia ? sp. 145

Fig. 34. One of the best preserved fragments referred doubtfully to this genus. Four-fifths natural size.



R. B. Johnson, Del.

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THE GEOLOGY OF THE CERRILLOS HILLS, NEW MEXICO.

BY DOUGLAS WILSON JOHNSON.

PART III. PETROGRAPHY.

The igneous rocks of the Cerrillos Hills have long attracted attention, more especially because of their association with the famous turquoise deposits and the anthracite coal of the region. The following pages represent an attempt to secure some evidence concerning the origin and method of occurrence of the turquoise, and to work out the relations of the associated rocks. The investigation of this problem was prosecuted with the aid of a grant from the Herrman Fund of the Council of the Scientific Alliance of New York.

With two minor exceptions, the igneous rocks of the Cerrillos region are of post-Cretaceous age. The exceptions consist of a few very small exposures of volcanic breccia and mica andesite, the former interstratified with Laramie (?) beds, and the latter with beds of the Colorado group.

The entire mass of the Cerrillos Hills proper is composed of rocks belonging to the augite andesite series, while a portion of the lower country to the east is formed by hornblende andesite. The intruded sheets or sills of the Madrid area south of the hills consist of a rock belonging to the hornblende andesite series, but showing trachytic affinities. Rocks of the olivine basalt series occur, forming Mount Calvary, and the low crater and surface flow northwest of the hills. Dykes of the augite andesite and basalt series are abundant. We have then, in the Cerrillos region, the following series of eruptives, given in the order of their relative ages, the oldest first:

1. Mica andesite series.
2. Eruptive breccias.
3. Hornblende andesite series.
4. Augite andesite series.
5. Olivine basalt series.

As these rocks occur in the form of interstratified beds, intruded sheets or sills, laccoliths, surface flows and dykes, the same rock occurring in several of these forms, a considerable variety of texture is developed. It is desirable, at the start, to define the rock names as used in this report, although the usage is not new, the classification being based on both textural and mineralogical variations.

An andesite is an igneous rock of porphyritic or felsitic texture, whose feldspathic component is dominant and is chiefly plagioclase, and which contains one or more of the following: biotite, hornblende, augite. According to which of the latter minerals is most prominent, we have mica andesite, hornblende andesite or augite andesite. If two of these minerals are present in a very notable degree, both are represented in the rock name, the name of the dominant mineral appearing first; as in hornblende-augite andesite.

By trachy-andesite is meant an igneous rock of porphyritic or felsitic texture whose feldspathic component dominates, and consists of more or less nearly equal amounts of orthoclase and plagioclase, and which has one or more of the following: biotite, hornblende and augite. It is thus intermediate between trachytes and andesites.

By gabbro-porphyry is meant a rock consisting of dominant plagioclase, and a monoclinic pyroxene, and which closely approaches a granitoid texture, but in which the pyroxene has its own crystal boundaries more or less perfectly developed. Texturally, the rock is intermediate between a true porphyritic augite andesite and its thoroughly granitoid representative, gabbro.

By augite monzonite-porphyry is meant a rock whose feldspathic component is dominant and consists of plagioclase and orthoclase in more or less nearly equal amounts, whose chief ferro-magnesian mineral is augite, and which closely approaches a granitoid texture, but in which the augite has its own crystal boundaries more or less perfectly developed. Mineralogically, the rock is intermediate between gabbro and augite syenite; and since the name monzonite is used to designate rocks intermediate between diorite and hornblende syenite, it seems desirable to apply the name augite monzonite to a rock which differs from the typical monzonite only in the presence of augite in place of the hornblende. Texturally, the rock is intermediate between a truly porphyritic trachy-andesite and its thoroughly granitoid representative, the monzonites.

Olivine basalt and limburgite are used in the usual well-established senses, the former to designate an igneous rock of porphyritic or felsitic texture with dominant ferromagnesian components, containing olivine, with its chief feldspar plagioclase; the latter to denote a similar rock in which the feldspar is absent.

By a rock "series," as the term is here employed, is meant the typical rock and those variations which appear to be merely mineralogical or textural variations of the same mass. Thus the augite andesite series includes the typical augite andesite, the gabbro porphyry, which is a textural variation of the same rock, and the augite monzonite-porphyry, which is both a mineralogical and textural variation of that same rock.

Although in the discussion of general geologic features, as set forth in Part I. of this report, the broader names of the several rock series alone were most frequently employed, it is desirable in connection with the detailed petrographical description to recognize the following subdivisions, which will be taken up in order:

1. Mica andesite series.
    (*a*) Mica andesite.
2. Eruptive breccias.
3. Hornblende andesite series.
    (*a*) Hornblende andesite.
    (*b*) Hornblende-augite andesite.
    (*c*) Hornblende-augite trachy-andesite.
4. Augite andesite series.
    (*a*) Augite andesite.
    (*b*) Gabbro-porphyry.
    (*c*) Augite monzonite-porphyry.
5. Olivine basalt series.
    (*a*) Olivine basalt.
    (*b*) Limburgite.

The discussion of the turquoise matrix is given in connection with the description of the augite andesite series, while the consideration of the turquoise itself is given in a final section.

LITERATURE.

In the literature of the region we find many references to the rocks of the Cerrillos Hills proper, as well as to the rocks composing the outlying hills. As a rule the determinations were made on megascopic characters only, and for the practical purposes of field records alone. Only the later observers made microscopic or chemical examinations, with a view to determining the rocks more closely.

Jules Marcou (1853) reports "trachyte et roche pyroxènique, trap," and says "Quelquefois ce trap est basaltiforme."* Professor W. P. Blake (1857) studied the turquoise deposits at Mt. Chalchihuitl, and described the rock as "a granular porphyry, yellowish, gray and white, in color; porous and earthy in texture. It decomposes rapidly by weathering, and very much resembles a sandstone."† This is the decomposed phase of the augite andesite, hereafter to be described. Dr. Newberry (1859) described the rocks composing the Cerrillos Hills as "wholly eruptive in character, mainly trap and trachyte," and the rock of Mt. Chalchihuitl as "a yellow porous trachytic porphyry."‡

Dr. F. V. Hayden (1869) does not refer to the nature of the eruptives of the Cerrillos district, but regards the Hills as composed of a dyke or a series of dykes.§ Dr. Oscar Loew (1874) regarded the Cerrillos Hills as composed of basalt and trachyte, and in his report gives an analysis of the turquoise.|| Professor J. J. Stevenson (1879) described the Cerrillos Hills as relics of huge trachyte dykes, and also reported the occurrence of basalt in the region.¶

Professor B. Silliman (1880) studied the turquoise deposits, and wrote: "These rocks are all eruptive rocks of the family of the augite trachytes."** In another place he refers to the "hard and tough hornblende andesite, or propylite, which forms the Cerro d' Oro and other Cerrillos Hills."†† Professor Silliman's determinations were based on microscopic examinations. Professor J. F. Kemp (1896) made a microscopic examination of the rocks in the Madrid area, a small suite of which were submitted by Prof. J. J. Stevenson, and published the results of his examination in connection with Professor Stevenson's report on "The Cerrillos Coal

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* Mississippi Railroad Reports, Vol. III., Pt. IV., p. 141.

† *Am. Jour. Sci.*, March, 1858, p. 229.

‡ Rep. of Expl. Exped. from Santa Fé, N. Mex., to Junction of Grand and Green Rivers, Macomb; Geol. Rep. by Newberry, p. 41.

§ Prelim. Field Rep. U. S. Geol. Surv. of Colorado and New Mexico, p. 67.

|| Rep. Chief of Engineers, 1875, Pt. II., p. 1027, 1028.

¶ U. S. Geog. Surv. west of 100th Mer., Vol. III. Supplement, pp. 329, 330, etc.

** *Am. Jour. Sci.*, July, 1881, p. 68.

†† *Ibid.*, p. 70.

Field." * Professor Kemp regarded these rocks as trachytes with close affinities for andesites.

Dr. C. L. Herrick (1898) noted one of the interstrata flows near the top of the Galisteo Monocline as being composed of "a characteristic leucite phonolite." † He regarded the southern part of the Cerrillos group as being composed of this phonolite, and the northern part of granite, and described the basalt flow northwest of the hills. In a more recent paper ‡ Dr. Herrick speaks of the Cerrillos Hills as having a small core of andesite surrounded by later material, the southern part of the group being composed of aegirine syenite.

The results of my own studies in the region are given below. Over two hundred typical rock specimens were secured, representing the phases of the eruptives occurring in all parts of the area. A study of over a hundred thin sections served to establish the characteristic types, as well as their areal limits with a fair degree of accuracy.

1. MICA ANDESITE SERIES.

(*a*) *Mica Andesite.*

Several interstata sheets in the district are composed of a very peculiar rock which is so greatly altered as to make its true characters difficult to ascertain. A couple of miles northwest of Waldo is exposed in Cretaceous shales, one of these sheets about two feet in thickness. The rock is dull grayish in color, evidently greatly decomposed, and is full of elongated cavities filled with calcite, some of which are nearly as large as a man's little finger. Under the microscope abundant rods of plagioclase and shreds of biotite can be seen, but little else can be made out, save the calcite. As in similar rocks larger pieces of biotite are also visible, I have regarded this specimen of one of the mica andesites. It seems most probable that the rock represents a surface flow in Cretaceous (Colorado) times, which was filled with steam cavities, and that the slow movement of the nearly solidified mass at this point produced the elongation of the cavities which were later filled with calcite derived from the surrounding shales. That this flow may have spread out over the floor of the Cretaceous sea is suggested by the occurrence of the fossiliferous shales immediately above and below the flow.

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* *Trans. N. Y. Acad. Sci.*, 1896, p. 122.

† *Bull. Univ. New Mex.*, Vol. I., pp. 109, 110.

‡ Report of Governor of New Mexico for 1900, p. 259.

Near the top of the Galisteo Monocline, 100 feet below the intruded sheet of augite andesite elsewhere referred to, a rock somewhat similar to the foregoing occurs as an interstrata sheet about a foot thick. This rock is darker than the former, but filled with small rounded masses of light substance, giving it a peculiar mottled appearance. Under the microscope the rock is seen to be a mass of spherulites of limonite-stained feldspars, with long, fine shreds of biotite (?) and occasional larger pieces of the same scattered throughout. Both the dark base of the rock and the light rounded masses are of the same spherulitic aggregates. Calcite occurs filling cavities. It seems not improbable that this rock is the same as the preceding, and that the calcite-filled cavities represent original amygdaloidal cavities. Fossils of Colorado age are found just above this sheet.

West of Cerrillos about a mile, in the shales dipping sharply away from the laccolith, is a small interstrata sheet of rock very similar to the preceding, except that it is much lighter and the rounded masses in it are less numerous. The microscope shows the remains of a few altered phenocrysts of plagioclase, while the great mass of the rock including the large light-colored spherules is made up entirely of beautiful little spherulitic aggregates (Plate Q, Fig. 1). Decomposition is too great to make out the minerals of the spherulites. Plagioclase is probably the main component, although a little green chlorite seems associated. Calcite is abundant.

If these three exposures are parts of one surface flow, as seems not unlikely, they represent the oldest rock in the region. If hornblende and augite occurred in this rock before its profound alteration, as is not impossible, or if they occurred in associated flows, we have a suggestion as to the age of the andesite fragments in the volcanic breccias found in the later Cretaceous beds of the Galisteo Group.

2. ERUPTIVE BRECCIAS.

East of the Cerrillos district, where the red sandstones of the Galisteo group have resumed the normal dip of several degrees to the east, occur large beds of eruptive breccia interstratified with the sandstones. The beds aggregate over a hundred feet in thickness, and are divided by occasional thin lenses of red sandstone. They represent the accumulations resulting from explosive out-

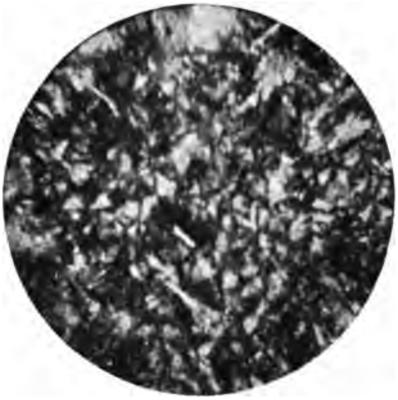

FIG. 1.—SPHERULITIC MICA ANDESITE (?). (Between crossed nicols.)

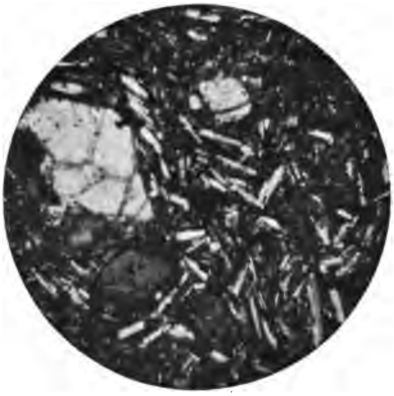

FIG. 2.—HORNBLENDE-AUGITE ANDESITE. (Between crossed nicols.)

bursts of some volcano situated near a shore-line of the late Cretaceous sea, whose successive periods of activity were only far enough apart to permit the formation of thin lenses of sandstone between the eruptions. That the ejectamenta fell in shallow water near the shore is indicated by the fact that the material is beautifully sorted and stratified, and lies upon sandstones in which horizontal fragments of tree trunks are found. None of this silicified wood was found in the breccia itself, but occurred at the top of the sandstone bed immediately under the breccia. The more extensive deposits of the "petrified forest" occur a short distance west, at a lower horizon.

The stratified character of these beds is well shown in Plate J, where the hammer is held at the contact with the underlying sandstones. The material varies in size from fine sand to boulders two and three feet in diameter. In some places consolidation has been developed to a fairly marked degree, and the breccia is used as ballast quite extensively by the Atchison, Topeka and Santa Fé railroad. It may be seen at various points along the road for many miles in either direction. The most accessible and extensive deposits occur near Ortiz, a station several miles farther east.

In the Cerrillos district are a number of exposures of the Galisteo group in the midst of the eruptive area, either turned up by one of the smaller laccoliths or caught up in the midst of the lava itself. In one instance the portion of this series containing the breccia was evidently thus caught up, for a little over a mile east of Grand Central Mountain is a limited area of the breccia, exposed in one of the small arroyos. The stratified character is well developed and shows a dip of several degrees to the west. At the western base of Mount Calvary, on the northern boundary of the district, is another small exposure of the breccia, dipping very gently northeast.

Under the microscope the breccia is seen to be composed of angular fragments of hornblende andesite, augite andesite, quartz grains, orthoclase, plagioclase and hornblende crystals, in a cement deeply stained with limonite. Occasional microcline suggests fragments from the old crystallines, while some of the orthoclase grains show beautiful zonal structure. Resorption of the hornblende in the andesite fragments was noted in a specimen from the locality east of Grand Central Mountain. Calcite as a decomposition product is abundant. No glass was observed, and it is evident that the fragments were torn from the solid rocks in depth and blown out in this condition. The resorption referred to must have taken place at a time previous to the eruption and wholly independent of it.

The andesite fragments are of a lighter color than the finer material found together with the deep red cement and are readily recognized. It is worthy of note that the two principal eruptives of the Cerrillos district are here represented, rocks of both the hornblende and augite andesite series. A careful comparison of these fragments with the types of the Cerrillos massive eruptions is difficult, because of the fragmentary and somewhat altered condition of the former. In general, however, the andesite fragments of the breccia correspond quite closely with some of the more decidedly porphyritic phases of the later intrusives. There is a pronounced and finely crystalline groundmass as a rule, while the feldspar phenocrysts, of both orthoclase and plagioclase, are better developed in some of the fragments than in the later rocks. In some cases these fragments are of hornblende vulsinite, hornblende being the only ferromagnesian mineral apparent, while orthoclase and plagioclase phenocrysts are present in nearly equal amounts.

That these andesite fragments are from rocks older than the Cerrillos andesite series there can be no doubt. The breccias containing them were formed in late Cretaceous times, during the deposition of the beds of the Galisteo Group. These beds and the interstratified breccias were upturned by the andesite intrusions forming the Cerrillos Hills. The evidence points to an andesitic magma which was tapped at successive geological times, yielding lavas of much the same general character.

3. HORNBLENDE ANDESITE SERIES.

(a) *Hornblende Andesite.*

The true hornblende andesite is confined to the eastern side of the Cerrillos Hills, constituting the country rock of the area drained by the tributaries on the northwest side of San Marcos Arroyo. Nearer Cerrillos the hornblende andesite is found on the southeast side of the arroyo, where it forms one of the smaller outlying laccoliths. The approximate areal limits are shown on the geological map.

As shown in the discussion of the general geology, the hornblende andesite is probably older than the rocks of the augite andesite series which compose the Cerrillos Hills proper, and occurs in the form of several laccoliths more or less intimately associated with each other. The rock is almost always somewhat decomposed, presenting a marked contrast with the usually fresh material of the later series.

In typical cases the rock is markedly porphyritic, phenocrysts of hornblende and plagioclase occurring in a finely crystalline groundmass. Magnetite as a rule is not abundant, and apatite is universally present in small amounts. Biotite rarely occurs in small shreds, usually more or less decomposed. Chlorite, and infrequent epidote, appear as alteration products. Calcite is quite common. Orthoclase may be present, but is usually very subordinate. Garnet was found in a specimen from half a mile west of the Reservoir in San Marcos Arroyo, while a little farther south a specimen showed occasional ilmenite with its characteristic decomposition product, developed along more or less definite rhombohedral directions. Titanite is rare.

The phenocrysts of plagioclase are usually much decomposed, so that the twinning is often greatly obscured. They may become quite large, giving the typical " bird's eye porphyry " appearance in the hand sample. Optical determinations show that the plagioclase is quite uniformly the variety oligoclase. Southwest of the reservoir in San Marcos Arroyo the andesite shows unusually fresh zonal feldspars, mostly plagioclase. In some cases calcite has replaced the more basic centers of these crystals. The hornblende is rarely well preserved, but occasionally shows fairly good crystals of the green variety. As a rule it is wholly gone over to chlorite, the outlines of the original crystal, however, being quite well preserved. Occasionally beautiful examples of the " Berlin blue " polarization effects are to be seen in this chlorite.

As a variation of the typical hornblende andesite we have a specimen from northwest of the reservoir which is composed almost entirely of plagioclase. Magnetite is very rare, and only a few small remnants of the hornblende are to be seen.

(*b*) *Hornblende-Augite Andesite.*

This phase (Plate Q, Fig. 2) of the andesite series differs from the foregoing in having a notable amount of augite among the phenocrysts. The augite is usually inferior to the hornblende in quantity and occurs as rather small, pale green, automorphic crystals.

The plagioclase is of the variety oligoclase, and as a rule occurs in smaller crystals than is usual in the preceding rock. The hornblende phenocrysts are almost wholly resorbed, a mass of small magnetite grains indicating the original form of the crystal. The augite, on the other hand, remains quite fresh in cases. Beautiful spherulitic chlorite is occasionally found, while calcite is not uncommon. Magnetite occurs often surrounded by reddish limonite. Apatite is rare, and a little orthoclase may be present.

This rock occurs half a mile northeast of Poverty Hollow, where it is surrounded by the typical hornblende andesite, and appears to be merely a phase of it. That the conditions were different in this portion of the magma is shown by two facts: Augite formed and remained; hornblende formed, but the conditions were such that after eruption it suffered resorption, whereas in the surrounding rock the hornblende remained, and was only changed at a later time, by secondary alteration, into chlorite.

A variation from the above type occurs at the western end of Grand Central Mountain, right in the midst of the augite andesite. In this case the hornblende has not been resorbed, but decomposed, forming an indistinct aggregate which seems to be chlorite. The apatites are unusually large, being short and thick. This may be an unusual phase of the surrounding augite andesite, or more likely an inclusion of the older hornblende andesite series. Near here is a large inclusion of Cretaceous shales.

Still another variation occurs in one of the interstrata sheets in the Madrid area. A section of the fairly fresh rock, brought up as a drill core, showed an unusually large proportion of the augite, while the hornblende was of a beautiful pale greenish-brown variety. The columnar habit of both the augite and hornblende is well developed, and long lath-shaped sections are frequently seen under the microscope. Magnetite occurs, and apatite is rather abundant. Calcite and pyrite are present in small amounts.

(*c*) *Hornblende-Augite Trachy-Andesite.*

This type of rock is characteristic of the Madrid area, where it occurs as intruded sheets or sills. It differs from the more widespread andesites of the Cerrillos district in its large percentage of orthoclase feldspar, thus making it intermediate between the andesites and trachytes. The feldspars occur as large phenocrysts and also in the finely crystalline ground mass, the plagioclase phenocrysts being of the variety oligoclase. The pale greenish-brown hornblende is much more abundant than the augite, which is of the light green variety. Both of the ferromagnesian minerals also occur as small shreds. The magnetite is only moderate in amount, and apatite occurs as usual ; titanite is rare. A few grains of quartz are also present, but are very rare. A little calcite is seldom seen.

A specimen from the eastern base of the Ortiz Mountains, in which group the sills of the Madrid area originate, shows the hornblende occurring about the outer edges of the augite, as a parallel growth. In this specimen there is considerable magnetite, and the apatites are unusually large and abundant.

4. Augite Andesite Series.

(*a*) *Augite Andesite.*

This is the most abundant rock of the Cerrillos district, and forms several of the larger peaks of the Cerrillos Hills proper, as well as several of the outlying smaller hills. It is also the most common rock in the dykes and sills surrounding the main laccolithic uplift.

Mineralogically the rock does not differ essentially from a true augite andesite. The typical variety is markedly porphyritic. Automorphic phenocrysts of pale green augite are abundant, occasionally showing the usual twinning phenomena. Not uncommonly inclusions of rutile needles forming "sagenite" webs are seen in the fresh augite. Of the usual inclusions magnetite and apatite are rarely quite abundant. In a specimen from east of the reservoir in San Marcos Arroyo, coming from a very small exposure of brecciated material, the augites are beautifully zonal, and occasionally show wavy extinction. The augite may also occur as a second generation in the ground mass, in the form of tiny rod-shaped crystals or shreds. In a specimen from the northwest base of Mt. McKensie the little rod-shaped crystals are abnormally developed, giving the section a very peculiar appearance. In the fresh rock forming the central portion of Turquoise Hill the augite phenocrysts are notably rounded by corrosion. In many cases the rock is more or less decomposed, and the augite is altered to epidote and calcite — more rarely to chlorite.

The feldspars occur in good automorphic or more fragmentary phenocrysts of plagioclase and rarely of orthoclase. The plagioclases range from andesine through the less basic of the labradorites. The usual twinning phenomena are observed, that according to the Baveno law being rare. Good zonal structure is occasionally seen. As the decomposition of the rock progresses, it is noted that the decay of the feldspars results in the obliteration of visible twinning phenomena before the crystal outlines are wholly obscured. All stages of the process are to be noted, and individuals which at first sight appeared to be a somewhat altered untwinned feldspar, with fair crystal boundaries, on more careful examination showed the faintest traces of albite twinning. It is possible that this may explain the statement by some that the rock in which the turquoise occurs contains only orthoclase feldspar, since the more unaltered portions of the same rock, only a few feet distant, contain few feldspars that are not undoubted plagioclase. The plagioclases also occur in the groundmass as small lath-shaped crystals and as irregular shreds. Frequently the groundmass is almost wholly composed of this feldspar, while in cases kaolinization is so extensive as to suggest its great abundance, although individual crystals are not recognizable.

Biotite is frequently present in small amounts, generally altered. It is sometimes most abundant about magnetite grains. Where fresh and in large fragments, it is of the brown, strongly pleochroic variety, changing from a pale yellowish-brown to a deep chestnut color. The magnetite may be quite rich, or may almost fail entirely. Apatite is not abundant as a rule, occasionally occurring as large, thick crystals. Zircon was noted in only one instance. In the more decomposed phases calcite and limonite are common. Pyrite is rare. Quartz was occasionally noticed, especially in the central portions of the laccolithic masses. In one of the large dykes, northwest of Waldo, little spherulitic aggregates of tourmaline were seen.

A peculiar phase of the andesite occurs as an interstrata sheet at the top of the Galisteo Monocline, west of the hills. The rock does not differ essentially from a true andesite, but contains a notable amount of an hexagonal mineral so badly decomposed as to make its identity a little uncertain. It seems most likely that it was nephelite. Dr. Herrick regarded the mineral as leucite, and on it probably based his reports of leucite phonolite from the region.

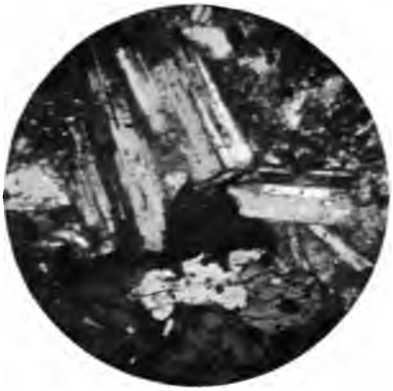

FIG. 1.—GABBRO-PORPHYRY FROM MT. MCKENSIE. (Between crossed nicols.)

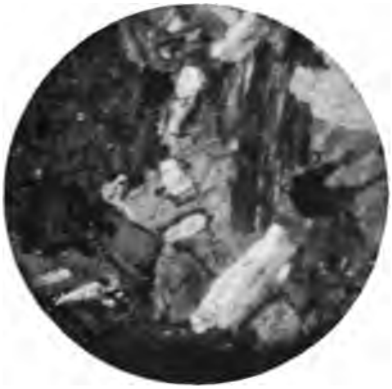

FIG. 2.—AUGITE MONZONITE-PORPHYRY FROM SANTA ROSA MOUNTAIN. (Between crossed nicols.)

In the same slide is a single section of a dark brown mineral which appears to be allanite. The augites of this rock are notably pleochroic.

In many of the radiating dykes of the region the porphyritic texture of the typical andesite is encountered, while in other cases the texture is noticeably different. Thus in some of the dykes east of the hills, the prominent dyke in Ortiz Arroyo south of Cerrillos, and the big Madrid dyke in Coal Gulch, we find few if any large phenocrysts. The rocks are fine-grained, as a rule, but almost entirely holocrystalline. Small rod-like crystals or shreds of augite are very abundant, together with rode-like and irregular plagioclases. Biotite is present in notable amounts, while considerable magnetite and very little apatite are seen. In one of the dykes east of the hills a little isotropic interstitial mineral was noted, which is probaly analcite. In the case of the Madrid dyke the augites are unusually abundant, and are of the violet-tinted variety more common in the basalts. These rocks are very similar to the camptonites of Rosenbusch.

(*b*) *Gabbro-Porphyry.*

On a textural basis we may establish a very important phase of the augite andesite, which is characteristic of the central portions of the greater laccolithic masses. The rock shows abundant automorphic crystals of augite, while the feldspars approach the granitic habit in their development, being more or less completely prevented by neighboring crystals from attaining perfect crystal boundaries. To this phase we might appropriately apply the name "gabbro-porphyry." It differs from the typical andesite in the absence of a distinct ground mass, and the approach to a granitic texture. The rock of Mt. McKensie (Plate R, Fig. 1) is a good example of this phase, while that of Grand Central Mountain is similar, but contains a notable amount of orthoclase. Biotite is fairly abundant in both of these rocks.

The gabbro-porphyry in the best preserved rock of the andesite series, and affords the best material for analysis. It is not probable that it differs materially in chemical composition from the porphyritic phases of the andesite just described. The chemical analysis, prepared by Dr. George Steiger, of the United States Geological Survey, is given under No. 1 in the table below.

A rock of very similar chemical composition is reported from the pass south of Mount Sneffels, Telluride quadrangle, Colorado.[*] It is called a gabbro-porphyry, and judging from the description differs mineralogically from our rock in the presence of hypersthene, the more pronounced groundmass and lack of large automorphic augites. The analysis of a plagioclase basalt from Saddle Mountain, Colorado,[†] is closely similar, being a little lower in alumina. A limburgite from Stein in Styria, Austria,[‡] is a little lower in silicia and higher in magnesia. These relations are more clearly shown in the following:

TABLE OF ANALYSES.

	1.	2.	3.	4.
SiO_2	48.21	47.32	48.76	46.76
Al_2O_3	17.96	16.71	15.89	17.93
Fe_2O_3	5.18	6.92	6.04	5.33
FeO	4.47	5.94	4.56	5.62
MgO	4.11	5.69	5.98	7.31
CaO	9.72	8.51	8.15	8.24
Na_2O	3.68	2.70	3.43	3.53
K_2O	2.99	2.02	2.93	2.20
H_2O+	1.41	1.04	1.48	1.83
H_2O-	.21	.24	.40	
CO_2	none.	none.	......	1.33
TiO_2	.84	1.50	1.65	trace.
ZrO_2	none.	......	none.	......
P_2O_5	.58	.96	.60	......
SO_3	none.	.19	......	......
Cl	......	trace.	......	......
MnO	.31	.08	.13	trace.
BaO	.07	.07	.17	......
SrO	trace.	.06	.06	......
Li_2O	......	trace.	none.	......
Total.	99.74	99.95	100.23	100.08

No. 1. Gabbro-porphyry from Mt. McKensie, Cerrillos Hills, New Mexico. Dr. George Steiger, analyst.

No. 2. Gabbro-porphyry from pass south of Mt. Sneffels, Telluride quadrangle, Colorado. H. N. Stokes, analyst.

No. 3. Plagioclase basalt from Saddle Mountain, Colorado. W. F. Hillebrand, analyst.

No. 4. Limburgite from Stein, Styria, in Austria. Herr Dr. Richard R. v. Zeynek, analyst.

The classification of the Cerrillos rock according to the scheme recently proposed by Cross, Iddings, Pirsson and Washington[§]

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[*] Bull. U. S. G. S. No. 168, p. 163, 1900.

[†] *Jour. Geol.*, Vol. V., p. 689, 1897.

[‡] *Tsch. Min. u. Pet. Mit.*, Band 17, S 534, 1898.

[§] "Quantitative Classification of Igneous Rocks," Chicago, 1903.

proves of interest. After calculating the molecular proportions of the chemical components of the rock from the complete analysis, and effecting the distribution of these components as mineral molecules, the percentage weights of the minerals were obtained and the *norm* established as shown below:

Formula.	Mol.		Wt.			Norm.				
$K_2O.Al_2O_3.6SiO_2$	32	×	556	= Orthoclase	=	17.79	F	60.00	Sal.	66.82
$Na_2O.Al_2O_3.6SiO_2$	36	×	524	= Albite	=	18.86				
$CaO.Al_2O_3 2SiO_2$	84	×	278	= Anorthite	=	23.35				
$Na_2O.Al_2O_3.2SiO_2$	24	×	284	= Nephelite	=	6.82	L	6.82		
$CaO.SiO_2$	77	×	116	= Diopside	=	17.11	P	17.11	Fem.	31.32
$MgO.SiO_2$	62	×	100							
$FeO.SiO_2$	15	×	132							
$2MgO.SiO_2$	41	×	70	= Olivine	=	3.79	O	3.79		
$2FeO.SiO_2$	9	×	102							
$FeO.Fe_2O_3$	33	×	232	= Magnetite	=	7.66	M	9.18		
$FeO.TiO_2$	10	×	152	= Ilmenite	=	1.52				
$3CaO.P_2O_5$	4	×	310	= Apatite	=	1.24	A	1.24		
				H_2O	=	1.62				
						99.76				

CLASS II.

$$\frac{\text{Sal}}{\text{Fem}} = \frac{66.82}{31.32} < \tfrac{7}{1} > \tfrac{5}{3}$$

Dosalane.

ORDER 5.

$$\frac{\text{L}}{\text{F}} = \frac{6.82}{60.00} < \tfrac{1}{7}$$

Germanare.

RANG 3.

$$\frac{K_2O' + Na_2O'}{CaO'} = \frac{92}{84} < \tfrac{5}{3} > \tfrac{3}{5}$$

Andase.

SUBRANG 4.

$$\frac{K_2O'}{Na_2O'} = \frac{32}{60} < \tfrac{3}{5} > \tfrac{1}{7}$$

Andose.

GRAD 1.

$$\frac{\text{P} + \text{O}}{\text{M}} = \frac{20.90}{9.18} > \tfrac{5}{3}$$

Andate.

SUBGRAD 1.

$$\frac{(Mg.Fe)O + CaO''}{K_2O'' + Na_2O''} = \frac{251}{0} > \tfrac{5}{3}$$

Andote.

From this it appears that the Cerrillos rock, which has been classified on a purely mineralogical basis as a gabbro-porphyry phase of true andesite, on the basis of the proposed chemico-mineralogical classification falls under *Andose.* Andose is a subrang of Rang 3, Andase, the type rock of which rang is the andesite of the Andes mountains. As shown by the calculation, the andose is dosalic (having the silico-aluminous non-ferromagnesian group of standard minerals dominant); is perfelic (extremely rich in normative feldspar); is alkalicalcic (having the alkalies and calcium in nearly equal amounts in the salic minerals); is dosodic (having soda dominant over potash); is prepolic (having the ferromagnesian silicates dominant over the ferromagnesian non-silicates); and premirlic (having the magnesium, iron and lime of the ferromagnesian minerals dominant over the alkalies of these same minerals). Accordingly the rock belongs in Class II., Dosalane; Order 5, Germanare;

Rang 3, Andase; Subrang 4, Andose; Grad 1, for which I suggest the name Andate; and Subgrad 1, for which I suggest the corresponding name Andote. According to Dr. Washington Grad 1 and Subgrad 1 are the most typical and common for the Andoses, a very large group. For this reason it seems best that they should be known respectively as andate and andote. The type of this magma represented by the Cerrillos rock might be known as the "cerrillal type," and the habit as the "cerrilloid habit," following the outline suggested by the authors of the new scheme.

The chemical analyses of Nos. 2, 3 and 4, in the preceding table of analyses, were suggested by Dr. Washington as showing the composition of other closely related rocks, all of them belonging in andose, and having low silica. It is thus seen that a gabbro-porphyry, a plagioclase-basalt and a limburgite are grouped together under the same subrang, being chemically much alike although differing widely mineralogically.

The Cerrillos rock furnishes a good example of one of the objections urged against the proposed classification, viz.: the difference between the standard mineral composition, or norm, and the actual mineral composition or mode, as determined under the microscope. The standard mineral composition gives for the rock about eighteen per cent. of orthoclase, seven per cent. of nephelite, seventeen per cent. of diopside, and four per cent. of olivine. Actually (modally) the rock contains little or no orthoclase, no nephelite, diopside or olivine, but a goodly percentage of augite and biotite not shown by the norm. On the other hand, a notable amount of orthoclase is present in the rock of some of the neighboring peaks, while a decomposition product from what may have been nephelite is found in a sill several miles west of the Hills.

According to a note from Dr. Washington "The normative orthoclase and olivine are present modally in the biotite. As the pyroxene contains undoubtedly a considerable percentage of the pure "augite" molecule $(Mg, Fe)O.Fe_2O_3.SiO_2$, this mineral will take up most, if not all, of the normative magnetite (and ilmenite). The normative diopside will also enter into this mineral. This transfer of Fe_2O_3 from magnetite to augite will bind an amount of SiO_2 equivalent to the Fe_2O_3 so transferred, leaving less silica available for combination with the Na_2O, and thus increasing the potential amount of nephelite. As, however, we have shown that in the biotite of such rocks the ratio of (Mg, Fe)O to the K_2O is about 5 : 1, it is evident that, to satisfy these conditions, some of the (Mg, Fe)O of the hypersthenic molecules of the normative diopside must exist modally as olivine molecules in the biotite. As olivine is an orthosilicate, silica will thus be made available, which will compensate for that taken up by the Fe_2O_3 in forming augite from the normative magnetite. As the amount of normative nephelite is considerable, however, it seems probable that this will not be entirely sufficient to change all the normative nephelite into albite, and that consequently some modal nephelite is actually present. It is possible also that the pyroxene contains some of the soda as acmite, which, having a ratio of SiO_2 to Na_2O of 4 : 1, will tend to lessen the amount of nephelite. The pyroxene present will then probably be composed largely of wollastonite and augite molecules, with a small amount of acmite."

It may be objected that the chemical analysis shows too small a percentage of silica (48.21 per cent.) to warrant the reference of the Cerrillos rock to a phase of andesite. Under the microscope, however, the feldspars are seen to be so far in excess of the ferromagnesian minerals as to rule the rock out of the basaltic group, according to our usual conception of the latter. The more peripheral portions of the same mass show a typical porphyritic andesite.

(*c*) *Augite Monzonite-Porphyry.*

This rock is similar to the "gabbro-porphyry" phase of the augite andesite, except that the orthoclase is about equal to the plagioclase in amount. It forms the large laccolithic masses of Santa Rosa, Santa Rosita, and Achavica Mountains, and one or two of the smaller hills.

The pale green augite is quite abundant, often in perfectly bounded crystals, and contains inclusions of magnetite, apatite, and sagenite nets of rutile needles. The orthoclase and plagioclase crystals rarely have good boundaries, approaching the granitic habit in their development. The plagioclase varies from andesine through the more acid labradorites. Strongly pleochroic biotite is fairly abundant, but is notably inferior to the augite in amount. The color changes are from a straw yellow to a chestnut brown. Magnetite is fairly abundant, and apatite is present, often in large, thick, but short crystals. Very rarely a stray quartz grain is encountered. There is no groundmass, but occasionally a little interstitial filling of analcite (?) is seen.

In cases where the rock is somewhat decomposed a little calcite is observed, and considerable secondary quartz. Biotite may also occur as small shreds, especially about magnetite grains.

A specimen from Gray Hill differs from the above type in that the rock is porphyritic, the feldspar phenocrysts are nearly all orthoclase, and little or no biotite is present. The groundmass contains abundant rods of feldspar which appear to be plagioclase. Titanite occurs and much augite is present in the groundmass in the form of small shreds.

(*d*) *The Turquoise Matrix.*

A discussion of the augite andesite series would not be complete without a special consideration of the greatly altered form in which the turquoise deposits occur. In addition to being present throughout the whole field in connection with mineral veins and shear zones, this altered andesite forms several broad areas which are indicated on the map. The rock is yellow or white in color, and might be mistaken for an altered sandstone by the casual observer. Even in the hand specimen, however, remnants of feldspar phenocrysts are easily seen, and the true character of the rock readily discerned.

The rock has been microscopically and chemically examined by several observers interested in the turquoise deposits which occur in this altered phase at Mt. Chalchihuitl and Turquoise Hill, as well as in minor quantities at other localities in the district. In 1881 Professor Benjamin Silliman gave us a description from which I quote the following: "The rocks in which the turquoise occurs are seen, by the aid of the microscope and polarized light, in thin sections, to be plainly only the ruins, as it were, of crystalline trachytes; they show fragments of feldspar crystals, decomposed in part into a white kaolin-like substance, with mica, slag and glassy grains, and quartz with large fluidal enclosures, looking like a secondary product." *

In Bulletin No. 42 of the United States Geological Survey, F. W. Clarke and J. S. Diller give a detailed microscopical and chemical discussion of "Turquoise from New Mexico." From their paper I quote the following description of the country rock: "Under the microscope the rock is seen to be composed chiefly of feldspar, with a considerable amount of biotite, epidote, pyrite, and limonite, and some amorphous substance. It is somewhat micrographitic in structure, and the irregular, interlocking grains of feldspar vary in size from .01 to .8 mm. in diameter. Most of them are considerably kaolinized, so as to appear cloudy in ordinary light; but between crossed nicols the original outlines of the grains become more distinct. Their optical properties indicate that the feldspar is orthoclase, an opinion which is fully borne out by the subjoined analysis of the rock, which shows a remarkably large proportion of potash (analysis quoted below). The porphyritic crystals are generally Carlsbad twins with irregular outlines. There are occasionally small grains of fresh transparent plagioclase which has evidently resulted from alteration.

" The biotite of the rock occurs in noteworthy quantities, but is very unequally distributed. It is frequently aggregated in groups of scales and may be seen most abundantly in small cavities. It sometimes occurs intimately associated with the turquoise, but unlike the latter it is one of the primary minerals. The small quantity of quartz present is a secondary product, so intimately associated with turquoise as to suggest their genetic connection. Pyrite is scattered rather uniformly throughout the rock in small cubical crystals easily seen in the hand specimen. They are sometimes altered to limonite, but in other cases they have been completely replaced by pseudomorphs of epidote. The specimen of rock which was subjected to analysis probably contained an amount of pyrite rather greater than the average. One of the most important constituents of the rock, because of its very close association with the turquoise, occurs in the form of bright yellow grains. * * * Judging not only from the properties enumerated, but also from the percentage of lime in the rock, this mineral is in all probability epidote. It is evidently connected genetically with the turquoise, for it is almost uniformly found upon the border of the latter and is most abundant in its neighborhood. * * *

" The occurrence of this veritable orthoclase rock in the West is of special interest from the fact disclosed by recent investigations that in many of the rocks previously described as trachytes the predominating feldspar is plagioclase." †

A study of more than a dozen thin sections of the altered rock has convinced me of its original identity with the surrounding augite andesite. Where the rock is not too thoroughly decom-

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* *Am. Jour. Sci.*, 1881, p. 70.

† Bull. U. S. Geol. Surv., No. 42, pp. 43, 44.

posed, distinct traces of albite twinning of the feldspars can be made out. The continued alteration results in the obliteration of this twinning even before the crystal outlines are wholly destroyed. Twenty-five yards east of the eastern excavation of the turquoise mines of Mt. Chalchihuitl a specimen was secured in which the feldspars showed fairly well preserved twinning according to the albite law; and even right in the excavation a sample was collected less completely altered than the most of the rock, which showed abundant evidence of this form of twinning. From the pit of the main excavation on the west side of the hill a sample was gathered containing several veinlets of turquoise. A section of this specimen showed the albite twinning distinctly enough to leave no doubt as to the fact that most of the feldspar phenocrysts were plagioclase. A very small per cent. of the phenocrysts seen might be regarded as orthoclase. The orthoclase may be more abundant in the groundmass, but it does not appear so. The plagioclase was not secondary, but was profoundly altered with crystal outlines yet remaining. A few yards farther west, away from this altered zone, the rock shows abundant fresh plagioclase, as the chief feldspar.

Of the large number of specimens gathered by me from the excavations themselves, from the vicinity of the mine, and in the adjoining country, there was none that would be called a trachyte, and I cannot doubt that the bulk of the rock in which the turquoise occurs was, in its unaltered state, identical with the andesitic rocks of the rest of the region. It seems hardly possible that the analysis given by Clarke and Diller can represent the usual character of the rock. So large a percentage of potash (11.18 per cent.) is extraordinarily high, even for a trachyte, and demands a rock very largely composed of orthoclase, wholly unlike anything found in the Cerrillos region by the writer. The petrographical description of the rock by Clarke and Diller shows the feldspars to be "considerably kaolinized, so as to appear cloudy in ordinary light." Under these conditions we should expect the rock to lose more or less of its potash, so that the high percentage is yet more difficult to understand.

Aside from the observations on the feldspars, my own conclusions from the study of these rocks did not differ materially from those quoted above at some length. Biotite was occasionally seen in irregular patches, sometimes largely altered to chlorite. Very rarely remnants of the augite were visible. It is noteworthy that this mineral is entirely gone in specimens which retain the feldspars fairly well preserved. Magnetite was rarely to be seen, while apatite was quite uncommonly noted. In the groundmass distinct plagioclase rods were discernible in one instance, but kaolinization obscured the whole mass as a rule. Pyrite, limonite, and epidote occur. Chalcedonic quartz fills irregular cavities in the rock at Mt. Chalchihuitl, while quartz in crevices and veinlets is common. In some cases these quartz veins are crushed, showing that the shearing had not ceased when the veins were formed. This crushing is also discernible in the feldspars at some localities.

The amorphous mineral referred to by Clarke and Diller is probably fluorite, as I find an isotropic mineral which appears to be fluorite fairly common in the rock with the turquoise in the main excavation at Mt. Chalchihuitl. In the excavation on the eastern side of the hill there is considerable tourmaline, from pale violet to deep blue in color, occurring as irregular fragments as a rule, but also as small, fairly well-bounded crystals.

Of the chemical analyses given below, No. 1 represents the fresh, coarse-grained variety (gabbro-porphyry) of the augite andesite from Mt. McKensie, a mile north of Mt. Chalchihuitl. While it cannot be said that this analysis represents the original fresh rock which in its altered phase contains the turquoise, the mineralogical

	No. 1.	No. 2.	No. 3.
SiO_2	48.21	56.68	52.38
Al_2O_3	17.96	16.62	33.49
Fe_2O_3	5.18	6.50	
FeO	4.47	......	.....
MgO	4.11	.79	1.17
CaO	9.72	.59	trace.
Na_2O	3.68	1.03	......
K_2O	2.99	11.18	......
H_2O+	1.41	3.28	12.88
H_2O-	.21		
CO_2	none.	......	......
TiO_2	.84	......	......
ZrO_2	none.	......	......
P_2O_5	.58	.73	none.
SO_3	none.	......	......
S	none.	.....	......
FeS_2	......	2.21	......
NiO	none.	......	......
MnO	.31	1.02	......
BaO	.07	......	......
SrO	trace.	......	......
CuO	......	trace, undet.	......
Total.	99.74	100.63	99.92

evidence shows that there could have been no great difference in composition. Certainly this analysis must be closer to the original composition of the turquoise matrix than No. 2, which is the analysis given by Clarke and Diller for a somewhat altered phase of the matrix. No. 3 is a partial analysis of the kaolin of a completely kaolinized portion of the rock containing much pale blue turquoise of earthy texture, also by Clarke and Diller. Except for the remarkable percentage of potash already referred to, Nos. 2 and 3 might well be derived from No. 1 by the processes of alteration which went on in the crushed zone about Mt. Chalchihuitl.

That the 33.49 per cent. given for alumina and ferric iron in analysis No. 3 is largely alumina is indicated by the fact, noted in the original paper, that the kaolin itself was white, although the alumina from it was distinctly reddish with the iron.

The study of the turquoise itself is discussed in a subsequent section.

5. Olivine Basalt Series.

(*a*) *Olivine Basalt.*

Northwest of the Hills is a low volcanic crater and lava flow of olivine basalt. The rock is dull reddish-brown to black, and very vesicular.

Under the microscope the rock is seen to be composed of beautiful olivines surrounded by abundant plagioclase (basic labradorite) rods and shreds of nearly colorless augites. Magnetite is very abundant, and limonite stains give the rock its red color nearer the crater. Serpentine occurs as an alteration product from olivine.

(*b*) *Limburgite.*

The radial dykes associated with the above flow, as well as the rock of Mt. Calvary, belong to the feldspar-free limburgites.

The augites are extremely abundant, have a broadly lath-shaped outline most frequently, and are of the beautiful violet hue characteristic of the titanium-bearing variety. The olivine is fairly abundant, sometimes being more or less altered to serpentine. Biotite occurs in small amounts, magnetite is very abundant, apatite rare. There is sometimes seen what appears to be a little interstitial analcite.

In the more decomposed specimens calcite is abundant, and the olivine has largely gone over to serpentine. Occasionally irregular patches of secondary feldspar are seen. Chlorite was also noted.

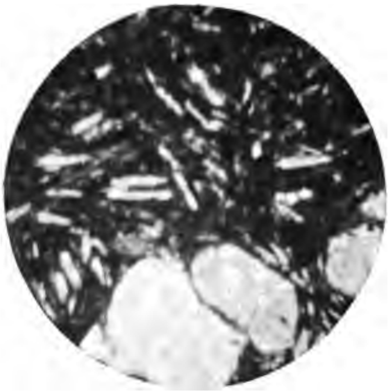

FIG. 1.—OLIVINE BASALT. (Between crossed nicols.)

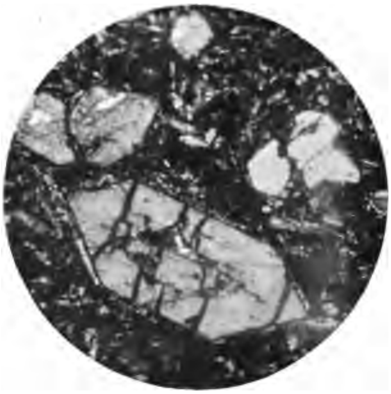

FIG. 2.—LIMBURGITE FROM MT. CALVARY. (Between crossed nicols.)

The rock of Mt. Calvary is not markedly different from that in the dykes. The latter would be referred to the monchiquites according to Rosenbusch's classification. The fact that the rock of Mt. Calvary is compactly crystalline, and shows no evidence of having been formed on the surface, while there is no indication of any lava flow, would suggest that the hill was of laccolithic origin. Such an hypothesis, however, necessitates the assumption of two limburgites, closely similar in character, of widely different ages, with an intermediate (in time) flow of a typical basalt, rich in feldspar. While not impossible, this appeals to one as rather improbable. On the other hand, to regard this hill as the neck of a volcano of more recent age than the basalt volcano to the southwest, forces one to assume that a crater and flow existed at a higher level than the basalt flow, and that they have been completely eroded, both of which assumptions seem to be contradicted by the field relations. If the hill itself represent a small overflow from a dyke or other conduit of the same age as the limburgite dykes, it is difficult to understand how the rock it so dense and hard, while the older overflow of basalt is extremely vesicular.

The Turquoise.

The turquoise of the Cerrillos Hills has been described at some length by Clarke and Diller, and early attracted the attention of geologists to the region. The gem occurs in veins throughout the sheared and altered zones of the augite andesite, and as little nodules in streaks of kaolin filling crevices in the rock. The color varies from green through greenish-blue to pure sky blue. As stated by Clarke and Diller: "The dark green nodules often shade off to nearly white at the center. * * * Many of the specimens are seamed or streaked by limonite, which has been derived from accompanying pyrite; and the latter mineral occasionally is found, bright and unaltered, inclosed completely in masses of clear blue turquoise." * Streaks of white kaolin, or kaolin slightly colored by limonite, are also common, destroying the value of much of the material.

Concerning the optical properties of the turquoise from this locality, Clarke and Diller write as follows: "Although deeply colored in the hand specimens, the thin sections appeared almost clear and transparent. Between crossed nicols the deep blue and green forms were seen to be composed of minute grains or short, thick fibers, but in the paler varieties the fibrous structure was more pronounced. The optical properties of both grains and fibers are the same throughout. They are all weakly doubly refracting, but have a rather high refractive index. The finely granular portions have a pale bluish aggregate polarization, less intense than that of chlorite, but when the mineral is distinctly fibrous it polarizes like some forms of serpentine, with light colors of the first order. The fibers are somewhat bent and interwoven, but lie approximately in the same direction. Each fiber becomes dark when parallel to the principal section of either of the crossed nicols, indicating that they must crystallize according to the quadratic, hexagonal, or rhombic system, instead of in one of the inclined systems, as was the case with the fibers studied by Bücking in the turquoise of Fresno County, California.

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* *Ibid.*, p. 39.

A section was prepared of a distinct vein of pale green turquoise, which showed that the fibrous structure is directly across the vein perpendicularly to its walls. Small fissures, running into or across the veins, have the fibers of turquoise arranged perpendicularly along their sides, just as serpentine arranges itself along fissures in olivine. Sometimes the fissures are minute and curved; but the resulting arrangement does not simulate the radial fibrous or spherulitic stucture described by Bücking as found in the turquoise of California, Nevada and elsewhere."

A study of a number of thin sections of the turquoise served to confirm, in the main, the observations above recorded. It will be seen, however, that the radial arrangement of the fibers was frequently noted, while the extinction of these fibers was found to be apparently slightly inclined, rather than parallel.

Under the microscope the turquoise is frequently seen as thin seams or stringers running throughout the rock. As a rule these seams are formed of more or less nearly rounded aggregates of the turquoise, sometimes packed closely together, the intervening spaces also being filled in part with turquoise; while in other cases these rounded aggregates are not so closely packed, and an isotropic mineral, probably fluorite, helps to fill in the interstices. Limonite and epidote may also appear in the latter association. This peculiar structure of the turquoise is shown in Plate T, Figs. 1 and 2; also Plate U, Fig. 1; which represent seams of the gem occurring in the altered andesite of Mt. Chalchihuitl.

Each one of these rounded aggregates is seen to be composed

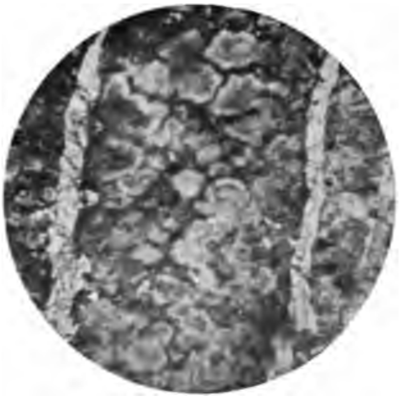

FIG. 1.—VEINLET OF TURQUOISE FROM MT. CHALCHIHUITL, SHOWING THIN SEAMS OF PROBABLE FLUORITE ON EACH SIDE SEPARATING THE TURQUOISE FROM THE MATRIX OF ALTERED ANDESITE SHOWN AT THE EXTREME RIGHT AND LEFT. (Ordinary light.)

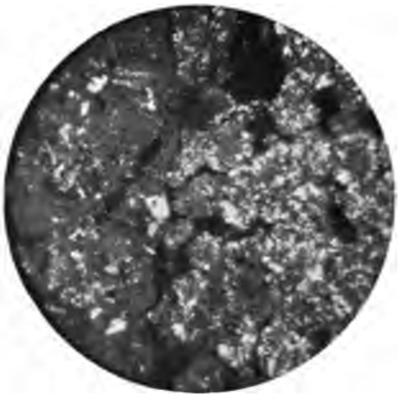

FIG. 2.—TURQUOISE FROM MT. CHALCHIHUITL IN RIGHT HALF OF FIGURE, IN CONTACT WITH MATRIX SHOWN AT THE LEFT. THE INTERSTITIAL ISOTROPIC MINERAL, PROBABLY FLUORITE, IS REPRESENTED BY THE BLACK AREAS IN THE RIGHT HALF OF FIGURE. (Between crossed nicols.)

of fine, thread-like fibers, radiating outward from the center of the mass, giving a true spherulitic structure. In some cases these spherulites also exhibit concentric, shell-like layers, more or less distinctly developed. Most frequently these spherulites have a dull, earthy gray center, outside of which is a lighter area, while the extreme outer border appears decidedly darker in cases. The dull gray center often appears nearly or quite structureless, but the spherulitic arrangement of the fibers is well shown throughout the surrounding light band. The interstitial filling, like the borders of the spherulites, may become quite dark and impure in appearance.

In some instances the turquoise is more massive, and the spherulitic structure very imperfect, or wholly wanting. When the latter is true, the fibers run across the vein, perpendicular to the walls being approximately parallel to each other.

The fibers, in both the spherulites and in the seams where the fibers are nearly parallel, appear to extinguish at a low angle. The determination of this point is not easy, but wherever the evidence was at all plain, there seemed to be little doubt of the inclined extinction. The polarization colors are generally pale gray-blue or straw yellow, the mineral being rather weakly doubly refracting. When a section of the more massive variety is cut parallel to the walls of the vein, *i. e.*, perpendicular to the fibers, the microscope shows a fine, granular aggregate, with aggregate polarization.

Reference has already been made to the occurrence of the isotropic mineral most closely resembling fluorite, which is associated with the turquoise. The method of its occurrence is well shown in Plate T, Fig. 1. Here the fluorite (?) is seen as small seams on either side of the vein of turquoise, separating the latter from the matrix of altered andesite, and also less distinctly as an interstitial filling between the spherulites of turquoise in places. In Plate U, Fig. 1, one of the seams of fluorite (?) is seen to widen out to much greater proportions, while the occurrence of this mineral as an interstitial filling is better shown.

The appearance of the turquoise, as seen in the above relations, strongly suggests the crystallizing out of the gem from solutions in small fissures, excluding the molecules which later formed the fluorite. If, as is believed, these solutions represented in part the original apatite scattered throughout the country rock, the occurrence of fluorite would be quite natural. The evidence does not seem to me to suggest the formation of the turquoise by alteration of vein apatite formerly occupying these same fissures.

No cases of veinlets of turquoise with transverse fibers penetrating larger seams of the same gem, such as were reported by Clarke and Diller, were seen in the sections examined. Their occurrence would not be unnatural, no matter what the origin of the turquoise might be, since they would represent recrystallization of the mineral in fissures opened in the older veins. Occurrences of this sort have been noted in fibrous serpentine, even where the latter did not represent replacement of olivine.

As noted in Part I. of this report, it seems most likely, in view of facts already referred to, that the turquoise is the original occupant of the fissures in the altered rock, rather than a secondary replacement of vein apatite. The fact that no evidence of vein apatite has ever been found in the region, and that the form of the turquoise in no case suggests its former presence, while of only negative value, nevertheless throws some doubt on the vein-apatite hypothesis. On the other hand, the appearance of the turquoise under the microscope, the manner of its occurrence in the veins and its relations to the associated fluorite (?), as well as the effectual disappearance of the usual content of apatite from the rock in the vicinity of the turquoise deposits, seem to favor the simpler method of origin: — that the gem is a secondary product, but the original occupant of the vein, — the alumina and phosphoric acid having been derived from the feldspar and apatite of the country rock, the copper being brought in from the same source (possibly indirectly) as the copper found in neighboring mineral veins. It seems not unlikely that this alteration of the rock was facilitated by hot solutions and vapors rising along the crushed and fractured zone. The presence of tourmaline, copper, pyrite, etc., is suggestive of some such action. Further reference to the origin of the turquoise appears in Part I. of this report. (The brief statement regarding the origin of the turquoise given at the very beginning of Part I. is misleading, and has been corrected in "Addenda et Corrigenda.")

Through the courtesy of Mr. George F. Kunz, of New York City, I was enabled to examine specimens of turquoise from near Silver City, New Mexico, and from Saguache County, Colorado, and through the kindness of Mr. N. W. Lloyd, of Pearce, Arizona, I was favored with a suite of specimens from this locality. While only small fragments of the matrix adhered to the specimens ex-

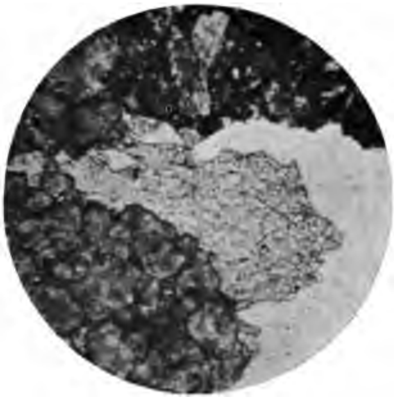

FIG. 1.—TURQUOISE FROM MT. CHALCHIHUITL (lower left hand part of figure) SHOWING UNUSUALLY LARGE AMOUNT OF FLUORITE (center of figure) AND PORTION OF MATRIX CONTAINING PLAGIOCLASE FELDSPARS (upper part of figure). (Ordinary light.)

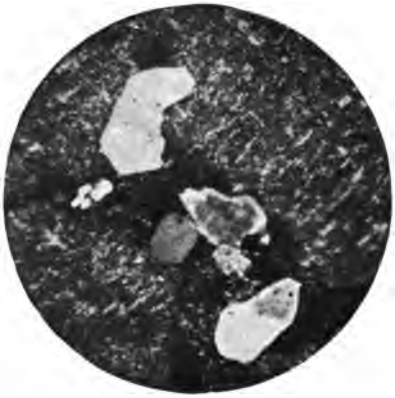

FIG. 2.—TURQUOISE FROM TURQUOISE GULCH, COLORADO, SURROUNDING CORRODED QUARTZ CRYSTALS. (Between crossed nicols.)

amined, it seemed evident that the veinlet from Silver City, New Mexico, filled a small fissure in quartzite. The turquoise from this locality was in part fairly massive, but portions of the vein showed a tendency toward the collecting in small, rounded aggregates. So far as I could determine the radial arrangement of the fibers in the rounded masses was very poorly if at all developed.

In the specimens from near Pearce, Arizona, the gem is seen to be very pure and massive, the entire sections showing little but pure turquoise. Sections were obtained both parallel and perpendicular to the walls of the vein, and when examined under the microscope showed a beautiful development of the spherulitic structure. The spherulites are not isolated as in the Cerrillos gem, but appear without definite borders, the whole mass being composed of imperfect but distinctly spherulitic aggregates of radial fibers in the finely granular "groundmass" — all of turquoise.

The gem from Saguache County, Colorado, shows a rather peculiar mingling of the radial arrangement of the fibers, and the arrangement perpendicular to the walls of the vein. For parts of the vein show many parallel fibers, perpendicular to the vein wall, and extinguishing together, while mingled with them are rounded areas with an imperfect development of the radial arrangement. In other parts of the vein the spherulitic structure is more pronounced, but is never so finely developed as in the Cerrillos or Pearce examples. A section of the Colorado material parallel with the walls of the vein showed a number of hexagonal cross-sections of quartz crystals, sometimes more or less corroded. It would appear that the quartz crystals formed on the walls of the open fissure, projecting out into the cavity, while the turquoise formed later. A section parallel to the walls would then cut these crystals at right angles to the axis *C*, showing the hexagonal outlines noted. Plate U, Fig. 2 shows an example of such an occurrence.

Several analyses of the Cerrillos turquoise have been made, and are recorded below. The earliest one of which we have mention is that given by Dr. Oscar Loew in 1875,* and is quoted as No. 1 in the following table. Nos: 2 (bright blue) 3, (pale blue, greenish cast), and 4 (dark green), are quoted from the paper by Clarke and Diller,† and were made in the Washington laboratory of the

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* Report Chief of Engineers, 1875 Part II., p. 1028.

† Bull. U. S. G. S., No. 42, p. 40.

United States Geological Survey. No. 5, given by Church for the Persian gem; No. 6, by G. E. Moore of turquoise pseudomorphous after apatite, from Fresno County, California; No. 7, by Nikolaieff of the mineral from Karalinsk in the Kirghiz Steppes; and No. 8, by Penfield of turquoise from Lincoln Co., Nevada, are tabulated for comparison.

ANALYSES OF TURQUOISE.

	1	2	3	4	5	6	7	8
H_2O	18.85	19.80	19.60	18.49	19.34	19.98	18.60	19.38
Al_2O_3	29.17	{39.53	36.88	37.88	40.19	35.98	35.79	35.03
Fe_2O_3	....	....	2.40	4.07	....	2.99	3.52	1.44
P_2O_5	29.57	31.96	32.86	28.63	32.86	33.21	34.42	34.18
CuO	4.04	6.30	7.51	6.56	5.27	7.80	7.67	8.57
SiO_2	12.57	1.15	.16	4.20	....	....	....	....
FeO	4.35	....	....	....	2.21	....	....	....
CaO	1.61	.13	.38	Undet.	....	....	....	....
MnO	....	....	....	....	.36	....	....	......
Insol.	....	....	....	....	....	....	....	.93
Total	100.16	98.87	99.79	99.83	100.23	99.96	100.00	99.53
Sp. gr.			2.805	2.426–2.651 (Blake)*	2.75	2.798–2.815	2.89	2.79

Concerning the large percentage of silica in No. 1 Dr. Loew says that he was very careful to separate the turquoise from all adhering trachyte, so that the silica must have occurred in the gem itself. Clarke and Diller say the same regarding the silica in No. 4. They consider the small amount of silica in No. 2 to be due to admixed rock from which the turquoise could not well be perfectly freed. The analysis of No. 2 is not complete because sufficient material was not available without the destruction of valuable specimens. In a paper referred to above† Silliman records 3.81 per cent. of copper, which corresponds to 4.78 CuO, but gives no other quantitative data.

Clarke and Diller discuss the analyses in some detail, and on the evidence furnished by them suggest the following formula for normal turquoise, $Al_2HPO_4(OH)_4$, considering the color due to the copper salt $2CuO, P_2O_5, 4H_2O$, which occurs merely as an impurity. The green varieties would then owe their color to added amounts of iron salts. Penfield, in his paper on "The Chemical Composition of Turquoise," ‡ discusses these same and additional analyses, and reaches the conclusion that the copper and small amounts of iron are not present as impurities, but are essential constituents of turquoise.

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* For similar specimens.

† *Am. Jour. Sci.*, 1881, p. 70.

‡ *Am. Jour. Sci.*, Vol. X., 1900, pp. 346–350.

SUMMARY.

In conclusion we may note the close andesitic affinities of all the rocks of the region, if we except the basalts. The few exposures of older Cretaceous eruptives show a rock belonging to the mica andesite group, while the later Cretaceous breccias are largely composed of andesitic fragments. The earliest of the post-Cretaceous outbreaks was a typical hornblende andesite, which was soon followed by rocks of the augite andesite series. The evidence points to an andesitic magma which has been tapped off at widely distant intervals, not yielding notably different lavas. The basalts are of still later age, and the evidence points to two different eruptions of this basic series, the limburgite dykes being intruded subsequent to the outflow of the true basaltic lava, as shown in Part I. of this report.

The matrix of the turquoise is shown to be greatly decomposed andesite occurring along sheared zones. The turquoise occurs as an alteration product, the alumina and phosphoric acid being derived from the feldspars and apatite of the country rock, while the copper was brought in by solutions that were probably active in effecting the decomposition of the rock. The microscopic features of the turquoise are discussed.

ADDENDA ET CORRIGENDA.

Part I. General Geology.

Page 1, line 15.—It should be added that the photographs from which Figs. 7, 10 and 12 were reproduced, were taken in connecion with this earlier work on the University Survey.

Page 4, line 29, *et seq.*—For this paragraph read: "(*g*) The turquoise occurs in altered portions of the andesite, and was formed as a secondary product from the alteration of the country rock, the alteration being caused by, and the copper in the turquoise probably contributed by, heated solutions (and vapors) rising along lines of fracture in the rock.".

Plates C and K.—From photos by C. H. Dague, of Cerrillos.

Plate I.—Drawn by R. B. Johnson from photo by E. F. Bennet, of Cerrillos.

Part II. Palæontology.

Page 121, line 4.—As suggested by Mr. T. W. Stanton, *Aucella strongi* is an *Inoceramus* probably referable to the section or subgenus *Volviceramus*.

Page 129, line 25.—On comparing my specimens referred to his *Tritonium kanabense*, with the type, Mr. Stanton expressed his conviction that the forms were not identical. He says: "The type of the species, which is the only one I have seen, as compared with your specimens, has straighter growth lines, straighter and relatively more prominent costæ, and slightly different spiral sculpture. It also has two important features of which I see no trace on your specimens, viz., a strongly dentate outer lip, and occasional prominent varices representing earlier apertures."

As it has been impossible for me to secure the opportunity of studying Mr. Stanton's types at the National Museum, I can only suggest the specific name "*cerrillosensis*" to designate this form in case it proves specifically distinct from Mr. Stanton's type. The figure of the latter, given in Bulletin 106 of the U. S. G. S., is so unsatisfactory that the reference seemed justifiable.

The Geology of the Cerrillos Hills, New Mexico

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